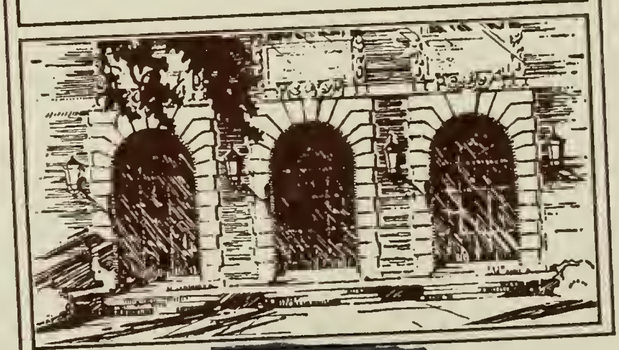

Report No. 308

COO-1018-1168

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Lawrence A. Dunn
Lakshmi N. Goyal
Bruce H. McCormick
Val G. Tareski

University of Illinois
Urbana, Illinois 61801

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1. INTRODUCTION

Automatic pattern recognition and graphical data processing have recently received considerable attention. In addition to analysis and processing of pictorial information, there is a need for interactive display systems to present both intermediate and final processed data. The subject of graphic display terminals has been extensively discussed in the literature. Scan-display systems oriented towards image processing, however, with particular attention to bypassing the central processing unit for as many tasks as possible have not had comparable development. This paper is focused on this latter area.

A computer system for image analysis and display has three principal constituents: image acquisition and display, image encoding for digital transmission, and finally procedures for classification of the encoded image. A new direction in image acquisition and display is to append a Video Communications Net to the central computer so as to provide the remote users with video transmission to centralized image processing facilities.

Requirements on image encoding for transmission of information are dependent upon application.[2] For example the bubble chamber data processing of high energy physics requires a very high positional resolution, although little demand is made on the gray-scale content of the picture. In the environmental sciences, however, gray-scale resolution is critical. Biomedical applications normally place stringent requirements on gray-scale resolution, but high positional resolution of the image is not required. Several systems are operative in high energy physics, such as PEPR[3] at M.I.T., CHLOE[4] and POLLY at Argonne National Laboratory, HPD[5] at Brookhaven National

Laboratory, and HUMMINGBIRD[6] at Stanford Linear Accelerator Center. Other systems are FIDAC[7] in biomedicine and KARLSRUHE[8] in automatic photointerpretation. However, we feel that these systems are unnecessarily specialized, and there is need for a more versatile and general system applicable to diverse disciplines on an integrated basis and amenable to modification as the need arises. In this paper we define an integrated system for the image acquisition and display.

Figure 1 shows the proposed system. Video switching matrix provides the facilities for remote users. High resolution CCTV cameras are provided for image encoding and acquisition. Remote video consoles, consisting of two high resolution monitors and a teletype set, provide information display at the remote user's end. Videograph printer outputs a fascimile copy at video rates, where the copy can have any admixture of text, graph or half-tone pictures. Microimage store provides the system with an extensive store of images — as direct images and not as digital data — and finds application in information retrieval areas such as library automation and biomedicine, where there is need for a permanent huge mass storage. High resolution scanners allow the scanning of the film for accurate measurement purposes and also allow the construction of images on film. High resolution monitors are slaved to the scanner system in a manner which allows the monitors to borrow inexpensively the scanner control. If video scan converters are part of the video switching matrix, video images can be treated as if they were on film and thus the same encoding techniques and the same programs could be exploited for both without program change. However, the video scan converter is not essential, since the controller can handle constraints of the video system with some sacrifice in resolution. Character generator provides facilities for message handling and display in general, particularly for CAI, which along with the scanner provides the flexibility of displaying line drawings and half tone pictures intermixed with the text. More details about the devices shown in Figure 1 are given in Appendix A.

Emphasis in the paper is given to inter-media transformation options — translation, magnification and rotation — that can be effected by control of position counters, to constraints necessary for maintaining media compatibility, and to alternate digital representations of an image. The major goal of the paper is to abstract the system parameters and to develop the relations among them. These system parameters are listed with their definitions in Appendix B.

Design values of these parameters for the Illiac III Scan-Display System are tabulated in Appendix C. For this system the format of the scan/display parameters is shown in Figures 18 and 19.

2. WAYS OF DIGITALLY REPRESENTING AN IMAGE

By selecting a grid and associated coordinate system an image can be represented as a digital string of encoded local samples. The coordinate system allows specification of a sampling position, or by implication a sampling sequence; and the grid mesh allows specification of a sampling resolution, or by implication a sampling frequency. One conventional image digitization procedure specifies sequential sampling along successive lines parallel to a specified coordinate axis. To describe these linear sweeps we will use the terms 'scan line' and 'scan axis'. Although several string definitions are possible each will always contain, either explicitly or implicitly, two correlated types of information:

> the coordinates of a point, and
> the image density level in some localized area about the point.

If the localized sampling area is not circular in shape then a third type of information can be included:

> local orientation of the sampling area.

The encoding/decoding format for these three items (position, density and orientation) is invariant in any given string definition. Any further interpretation of the string requires knowledge of the sampling technique employed.

Specifying a sampling sequence, a digital string representation can be formed in two different ways:

r) encoding the image density level for each coordinate in the sequence, or

c) forming an ordered substring of coordinates by selecting only those from the given sequence for which the image density level satisfies some prescribed criteria.

For a particular image each of the two strings is unique within the reproducibility limits of density detection and encoding.

String r) is usually more representative and economical (in terms of string length) for images with a frequently varying density, i.e., with large amounts of detailed information — as a page of text with illustrations or a stained tissue section.

String c) is more economical and representative for sparse images such as an engineering drawing or bubble chamber negative. For these images high resolution is needed along the scan axis but the scan lines can be relatively far apart without loss of information. A rectangular or slit-like sampling area is effectively employed if its orientation is within approximately 45° of being perpendicular to the scan line. However, to sample all possible orientations it is necessary to:

c1) sample each scan line several times — once for each of a sequence of orientations,

c2) sample a second sequence in which scan lines are perpendicular to those of the first.

String c) can be a function of the sampling technique, i.e., one can sample <u>for</u> and recognize <u>only</u> a preselected class of features. Two possible classes are:

c3) silhouettes, or images containing large areas of uniform density — adjacent areas are distinguished by a sharp discontinuity in image density. Chromosome karyotyping falls in this class.

c4) outlines, or sparse line drawings — these are a special case of silhouettes. The engineering drawings and bubble chamber negatives are in this class.

Sampling criteria corresponding to each of these classes can be stated as:

c3a) select the point if the <u>change</u> in image density between it and the previous point(s) exceeds some threshold.

c4a) select the point if the image density <u>increases above and then decreases below</u> some threshold between it and the previous point(s).

The image density level in each case can be recorded in the string representation along with the coordinates.

If it is known that the image contains line (or boundary) information -- perhaps from having processed a string obtained in one of the aforementioned ways -- then it may be useful to track the constituent lines by sampling a sequence of localized areas with restricted sets of orientations. This tracking procedure then generates a sequence of head-to-tail vectors or, in the limiting case, a string of incremental displacements. This concept is also useful in creating an image by first constructing the incremental string. A natural interpretation of the string is:

i) an ordered set of commands defining starting point, line width, line intensity and the (incremental) segment vectors.

Curved lines obviously can be represented as a sequence of sufficiently short segmental displacements.

These three ways of forming strings — r), c) and i) are correspondingly defined as the <u>Raster</u>, <u>Coordinate</u>, and <u>Incremental</u> data formats.

2.1 Raster Format

Stated in PL/1 the sampling algorithm for an X-axis scan including the optional orientation sampling is:

```
      IF ¬ SLIT then ΘB = ΘE;
  SY: DO   Y = YB BY ΔY TO YE;
  SΘ: DO   Θ = ΘB BY ΔΘ TO ΘE;
  SX: DO   X = XB BY ΔX TO XE;
      CALL ENCODE_OR_DECODE_G(Y,Θ,X);
      END SX;
      END SΘ;
      END SY;
```

where (XB, YB) and (XE, YE) define a rectangular area to be sampled at increments of (ΔX, ΔY). Each scan line is sampled once for each orientation from ΘB to ΘE at increments of $\Delta\Theta$.

The total number of samples is:

$$N_s = \text{Number of lines x number of orientations per line x number of samples per orientation}$$

and the number of bits required for storage is:

$$N_b = \text{Number of bits per sample x number of samples.}$$

2.2 Coordinate Format

Stated in PL/1 the sampling algorithm for an X-axis scan is:

ENCODING (READ)

```
      IF ¬ SLIT THEN ΘB = ΘE;
  SY: DO   Y = YB BY ΔY TO YE;
  SΘ: DO   Θ = ΘB BY ΔΘ to ΘE;
  SX: DO   X = XB BY ΔX TO XE;
```

```
          IF CRITERIA_SATISFIED THEN
CYES:        DO;
             IF FIRST_TIME_FOR_THIS (Y, Θ) THEN
             FYES:  DO; CALL OUTPUT (Y);
                    IF SLIT THEN CALL OUTPUT (Θ);
                    END FYES;
             FNO:   DO; CALL OUTPUT (X);
                    IF NGL >2 THEN CALL OUTPUT (G);
                    END FNO;
             END CYES;
CNO:         END  SX;
             END  SΘ;
             END  SY;
```

DECODING (WRITE)

```
INIT:        CALL INPUT (YIN);
             IF SLIT THEN  CALL INPUT (ΘIN);
             CALL INPUT (XIN);
             IF NGL >2 THEN  CALL INPUT (G);
SY:          DO  Y = YB BY ΔY TO YE;
SETΘ:        Θ = ΘIN;
             IF Y = YIN THEN
             SX:  DO X = XB BY ΔX TO XE;
                  IF X = XIN THEN
             MOD: DO; CALL MODULATE_BEAM;
                  CALL INPUT(NEXT_COORDINATE);
                  IF THIS_IS_A_NEW_Y(NEXT_COORDINATE) THEN
             NEWY:DO; IF SLIT THEN CALL INPUT(ΘIN);
                 YIN = NEXT_COORDINATE; CALL INPUT(XIN);
                  IF NGL >2 THEN CALL INPUT (G);
                  GO TO SETΘ
                  END NEWY;
```

```
NOTNEWY:  XIN = NEXT_COORDINATE;
          IF  NGL > 2 THEN CALL INPUT (G);
         END  MOD;
         END  SX;
         END  SY;
```

where (XB, YB) and(XE, YE) define a rectangular area to be scanned at increments of (ΔX, ΔY). In encoding each scan line is swept once for each of the orientations between ΘB and ΘE, where $\Delta\Theta$ is the orientation increment. Actual encoding takes place only when the criteria is satisfied. In decoding, only those scan lines which are specifically read in are swept at the input orientation, and writing takes place (or more generally, is initiated) only at those positions which match the input coordinates.

NGL is the number of gray levels. If this number is greater than two, additional encoding/decoding is necessary to obtain the gray levels. For NGL = 2, the fact that the criteria is satisfied implies the gray scale information.

The most general coordinate string of an X-axis scan has the form:

Y coordinate, Θ, X coordinate, gray scale,
   X coordinate, gray scale, X coordinate, gray scale...
Y coordinate, Θ, X coordinate, gray scale, ...

2.3 Increment Format

The incremental string is composed of a sequence of elements that can be interpreted either as a segment vector or as an incremental command. The segment vector is composed of two incremental displacements, DX and DY, the corresponding signs for each displacement, SX and SY, and the 'beam condition'. DX specifies the number of unit cells the beam is to

be displaced in the X direction and DY specifies the number of unit cells the beam is to be displaced in the Y direction. The beam condition is given as being either on or off during the move.

If (DX, DY) = (0,0), the two signs, (SX, SY), and the 'beam condition' are interpreted as an incremental command,where incremental commands have the following semantics:

H	Halt, close out the operation.
IT	ITerate (magnify) the next segment vector. The next two elements in the string should be a count followed by a segment vector.
MB	Modulate the Beam intensity (at a fixed position).
NOP	No OPeration
RGR	Reset Grid Resolution
RSO	Reset Stencil Orientation
RSS	Reset Stencil Size and/or shape
RVB	Reset Vector Begin point

The IT command with its count is equivalent to having the same segment vector appear sequentially in the string by the number of times given in the count byte. If the displacement is (0,0) the IT command is ignored.

The four commands that reset parameter values are followed by string elements containing the new parameter values. The element format is the same as that defined for the initializing parameter string.

For the incremental format (XD, YD) and (XE, YE) are interpreted as defining a file area, outside of which no recording (film) or displaying will be allowed to take place. (XB, YB) becomes the initial point from which the beam will start the first segment vector.

Figure 2 shows the use of incremental vectors with the command RSS inserted at point P (between vectors (2,2) and (3,1)) and with command RGR inserted at point Q.

3. RESOLUTION, SAMPLING AND SCANNING PARAMETERS

3.1 Resolution

In order to encode a digital representation of an image it is necessary to impose a grid and coordinate system upon it. It is convenient to conceive the total image or raster area as a unit square and to interpret the addressable positions of the image as fractional coordinates ranging between 0 and 1. The mesh of the grid superimposed on this range is then 2^{b_g} where b_g is the number of bits used to specify coordinate position. The smallest resolvable square has sides of 2^{-b_g} units and is termed a gross basic cell.

The aspect ratio of the raster area need not be 1 : 1. The physical interpretation of the basic cell will more generally be a rectangle, hence the effective resolution along one axis may differ from that along the other.

The adopted coordinate system — left-handed rectangular — is a natural one for most textual material and also corresponds to standard video practice of left-to-right top-to-bottom scanning.

In concept one achieves the physical limit of resolution by choosing b_g sufficiently large. In practice this is difficult to implement and one distinguishes between a gross position counter specified by b_g, and a vernier position counter specified by b_v. The vernier counter has a sign bit, s_v, and is interpreted as a signed position relative to the gross position. This is equivalent to overlaying a vernier grid in the immediate vicinity of a gross coordinate position (which can be interpreted as a local 'benchmark'). One then has a localized grid of mesh $2^{b_g+b_r}$ where b_r is the number of bits in the vernier counter used to extend the gross

resolution. The smallest resolvable square has sides of $2^{-(b_g+b_r)}$ units and is termed a vernier basic cell. The remaining b_o bits in the vernier counter define the gross-vernier overlap, or the maximum vernier window as having sides of 2^{b_o} gross basic cells, (see Figure 3) or $2^{(b_o-b_g)}$ units.

The above discussion defines the design parameters that determine maximum position resolution. Not all applications warrant this maximum resolution. More importantly one cannot contrive efficient scanning-recognition algorithms without a range of resolution options. One clearly wants independent choices of resolution for the two axes, either because the application warrants it, or because the format warrants it, as in the case when scanning in the coordinate format using a slit-like sampling area.

The parameters p and q specify the sampling resolution as every 2^p basic cells in the X-direction and every 2^q basic cells in the Y-direction:

$$\Delta X = 2^p \text{ basic cells} = 2^{p-(b_g+k)} \text{ units} \tag{1}$$

$$\Delta Y = 2^q \text{ basic cells} = 2^{q-(b_g+k)} \text{ units} \tag{2}$$

The gross/vernier selection determines k as $0/b_r$. The smallest resolvable rectangle is ΔX by ΔY units and is termed the unit cell.

The position counter is incremented at the p^{th} or q^{th} significant position of the gross/vernier counter, hence the number of significant position bits is:

	X	Y
raster gross:	$b_g - p$	$b_g - q$
raster vernier:	$b_g + b_r - p$	$b_g + b_r - q$

For the coordinate representation it is desirable to increase gross sampling resolution along the scan axis while incrementing the position counter at the p^{th} significant position as described above. This can be done by interpolating between counter increments and concatenating the b_c interpolation bits to the $b_g - p$ significant counter bits. One then has for the coordinate resolution:

coordinate gross: $b_g + b_c - p$ significant bits.

A natural choice is to make $b_c = b_r$ since b_r reflects the physical limit of resolution.

3.2 Sample Encoding

The maximum number of image density states for a read command or recording beam intensity states for a write command are indicated by the gray scale parameter, n. The number of encoded bits is interpreted as 2^n, hence the number of possible states as 2^{2^n}. The maximum value of n is specified as n_{max}.

Triggering or filtering of output information may be done by either a standard level discriminator or by a specially designed plug-in unit. The value assigned to the parameter T chooses between these two.

The parameter B_s will distinguish between the choice of a standard size spot (≃1 gross basic cell in diameter), and a slit or non-standard spot size. If the non-standard option is taken, then the parameters u and v define the sample width and length as 4^u and 2^v gross basic cells respectively. The range of circular spot sizes can be specified by u with v = 0.

If the sample area is slit-like then the orientation becomes significant. The unit of angle is the circle, or radians/2π. The angular resolution is 2^{-b_a} units where b_a is the number of bits used to specify an angle. The angular sweep Begin-End coordinates, (ΘB, ΘE), specify the range over which incrementing is to be accomplished. The increment is defined by

the parameter z as $\theta = 2^{z-b}a$ units. The slit is swept the length of a scan line for each value of θ in the specified range. Figure 4 illustrates the geometrical definition and angular reference.

3.3 Scanning Rate

Sweep velocity will in general be limited by the following:

1) positional digital-to-analog response time

2) maximum channel data transfer rate

3) number of bits of gray scale encoding/decoding

Sweep velocity can generally be expressed as a function of the following parameters (see Appendix B), where a constant clock rate for incrementing the positional counter is assumed:

$$\vec{V}_s = c_1 \cdot f(p,q,A) \cdot g(DF, K , n, n_{max}).$$

Here f is determined by the scan axis and unit cell selection:

$$f(p,q,A) = (1-A) \cdot 2^p \cdot \overrightarrow{\delta x} + A \cdot 2^q \cdot \overrightarrow{\delta y}.$$

The maximum continuous data rate is required for the Raster format with $n = n_{max}$, where g can be normalized as

$$g = 2^{-n_{max}}.$$

The data per sample is higher for the coordinate format, but the average data rate is normally less than for Raster. (Otherwise the image would be more optimally encoded in a raster format.) Buffering is needed to handle local bursts of perhaps 3 or 4 consecutive samples. The amount of data for coordinate representation is essentially (though not absolutely) independent of the number of bits of gray scale encoding/decoding.

For an X-axis scan at constant sample rate one then has

$$\vec{V}_s = c_1 \cdot 2^{-n_{max}} \cdot 2^p \cdot \overrightarrow{\delta x}.$$

c_1 can then be determined from the clock frequency. This equation yields a constant sample rate with the Raster format for any value of n.

Since the data per sample is 2^n bits, one obtains a constant data rate by introducing the quantity $n_{max} - n$ in the exponent yielding:

$$\vec{V}_s = c_1 \cdot 2^{-n_{max}} \cdot 2^{p+(n_{max} - n)} \cdot \overrightarrow{\delta x}.$$

Here instead of incrementing the position counter at the p^{th} significant position, the burden on the positional D/A conversion is appreciably lessened if one increments only at the $[p + (n_{max} - n)]^{th}$ significant position and interpolates to obtain samples at the $(2^{n_{max} - n}-1)$ positions between counter increments.

The constant data/sample rate option for a given resolution is then determined by the parameter K.

3.4 Window Area

The term window was introduced above in defining the maximum area that can be covered in a single operation with vernier resolution. Two pairs of coordinates serve to specify the portion of an image to be scanned, encoded and displayed. They are termed the Begin coordinates, (XB, YB), and End coordinates, (XE, YE), and are interpreted as defining diagonally opposed corners of a rectangle. Since the position counters may be decremented as well as incremented any one of four B-E combinations may be chosen to specify the same window area. This feature and the coupled-uncoupled option of the monitor position counters allow the Rotation Group transformations described below. The coordinates must be multiples of (ΔX, ΔY).

3.5 Scan Format (Lattice and Sequence)

The scan format, determined by the parameters L, S and A, imposes a Lattice upon the grid in terms of the unit cell and specifies the scan line sampling sequence. The scan axis is specified by A as X or Y, and S selects the scan line sequence as interlaced or sequential. These two parameters along with the B-E combination completely determine the sampling sequence. One obviously starts with the Begin coordinate and terminates with the End coordinate, determining the direction of sampling along a scan line. The hexagonal/rectangular lattice option is defined by L as described below.

The matrices in Figures 5 and 6 illustrate the sampling sequences for a scan direction parallel to the X-axis on a Rectangular Lattice. The position of point No. 1 in the lattices is specified by the Begin Coordinates. The End Coordinates specify point No. 42 in the Sequential case (Figure 5) and point No. 15 in the Interlaced (Figure 6) case. Since the Begin and End coordinates are constrained to be multiples of ΔX and ΔY they will always be member points of the Lattice.

Figure 7 illustrates the relative positioning of points and their sampling sequence for the two scan directions on Hexagonal Lattices when line sampling is sequential. The Hexagonal Lattice is obtained by shifting the lattice points of odd numbered scan lines in the corresponding Rectangular Format by an amount $\Delta X/2$ (or $\Delta Y/2$) along the positive scan axis. Otherwise hexagonal formats are analogous to their rectangular counterparts.

The Interlace option and the adopted coordinate system are particularly suited for communication with a standard video network through an analog-to-digital interface. Figure 6 shows the relation between the fields and the sample points for the interlace option.

Lines have been drawn between points surrounding point No. 11 in Figures 7(a) and 8 and point No. 17 in Figure 7(b) to illustrate the concept of neighbor points. An interior point of the Hexagonal Lattice has 6 neighbor points whereas that of the Rectangular has 8. Since the Hexagonal Lattice is not regular (it is rhombic), although it is nearly so for $\Delta X = \Delta Y$ (see Figure 7), neighbor points are not all equidistant from their interior point; but they always partition by distance into two sets of 4 and 2 points each. Those for the Rectangular Lattice partition generally into three sets of 4, 2 and 2 points each, and for $\Delta X = \Delta Y$ the two sets of 2 and 2 become a single set of 4. Compare Figure 8 with Figure 7.

4. VIDEO COMPATIBILITY

When interfaced by a video scan converter the video network can be handled as a scanner. However, the scan converter is not essential since the S-M-V Controller can be designed to satisfy the constraints of the video systems. The following discussion uses the parameter i to identify the video system within the network; it assumes the controller-video link to be direct and develops the corresponding constraints.

Since the video line sweep time, $\Delta t(i)$, is a fixed parameter the number of data bits that can be transferred to or from core per full scan line is constrained by the I/O channel capacity, where the maximum bit transfer rate is f_b. A buffer will allow a 'burst-mode' sampling for some fractional part of the scan line — hence higher resolution in sampling a vertical band can be achieved.

The Incremental string cannot be passed directly to video; it must first be passed to a scan converter.

The Coordinate string with video has a resolution along the scan line equivalent to Raster resolution with $n = n_{max}$, hence the scan axis counter increment, ΔC, is given by:

Raster with constant data rate option:

$$\Delta C = 2^{p+(n_{max} - n)}$$

Raster with constant sample rate and Coordinate:

$$\Delta C = 2^{p}.$$

One would normally choose the constant data rate option. The Coordinate string resolution can only be locally maintained because the buffer storage limits the number of successive samples in contiguous unit cells.

This is not a severe restriction since the coordinate representation is not very meaningful unless the image is rather sparse. Note that orientation sampling is meaningless with video.

The entire video discusssion is from the point of view of the Raster string representation. The string will have existence only when core memory participates; otherwise there is only the analog signal transfer between the other three media. The resolution results are valid independently of the point of view.

4.1 Horizontal (X-axis) Resolution

To achieve a maximal uniform resolution across a full scan line it is necessary to maintain a constant data rate. We choose the largest j such that

$$2^j \le f_b \cdot \Delta t(i) \tag{3}$$

and hence maximize and fix the number of bits in a full line of sampling. Position resolution and gray scale resolution are not independent: the number of bits per sample is 2^n, hence equation (1) constrains the number of samples in a full line to be

$$S(j,n) = 2^{j-n} \quad . \tag{4}$$

Maximizing position resolution minimizes gray scale resolution and vice versa. S(j,n) achieves its maximum value for n=0:

$$S_{max}(j) = S(j,0) = 2^j \tag{5}$$

Table I shows values of $S_{max}(j)$ for three different video systems. Parameter values used in the calculation are given in Appendix C. If a window contains only a fractional part of a scan line, then only a corresponding fractional part of $S(j,n)$ samples can be obtained along each scan line.

Sampling at the position counter stepping frequency, f_c, maintains the aforementioned data rate for an $2^{n_{max}}$ bit gray scale datum. An interpolation counter is used to achieve the rate for other choices of image density resolution with the constant data rate option:

$$\Delta C = 2^{p+(n_{max}-n)}.$$

A 1-1 correspondence between a full scan line at video and the S-M-V control grid requires:

$$S(j,n)\cdot\Delta X = 2^{b_g} \text{ basic cells.}$$

Substituting for $S(j,n)$ from equation (4) yields:

$$(\Delta X)_{max}(j,n) = 2^{b_g-(j-n)}, \text{ hence}$$

$$p_{max}(j,n) = b_g-(j-n). \tag{6}$$

This defines the achievable video resolution along scan lines as well as the largest useable sampling increment that may be associated with the S-M-V control grid scan axis. Table II illustrates the interdependence of position and gray scale resolution for the three video systems of Table I. It contains the values of $S(j,n)$ as constrained by equation (4), and in parentheses the corresponding maximum values of ΔX as given by equation (6). All parameter values used are listed in Appendix C. The function $g(j)$ is explained in the following section.

4.2 Vertical (Y-axis) Resolution

Having determined the video resolution along a scan line we now determine the vertical sampling so as to achieve a unit cell match to the S-M-V control grid. Assuming an X-axis scan at the controller, this constraint requires the video line sampling frequency to be

$$(\Delta Y)_v = \frac{r_v}{r_s} \cdot \frac{N(i)}{S(j,n)} \cdot \frac{\Delta Y}{\Delta X} , \qquad (7)$$

where r_s and r_v are the aspect ratios at the control grid and video, respectively. $N(i)$ is the number of lines per video frame. The unit cell resolution ratio at the S-M-V control grid is $\Delta X/\Delta Y$, and the corresponding video resolution ratio is $\frac{1}{S(j,n)} \; \frac{N(i)}{(\Delta Y)_v}$. Using equations (1), (2) and (4) equation (7) can be written as

$$(\Delta Y)_v = \frac{r_v}{r_s} \cdot N(i) \cdot 2^{q+n-p-j} ,$$

which may be restated as:

$$(\Delta Y)_v = f(j) \cdot 2^{q+n-p} ,$$

where $$f(j) = \frac{r_v}{r_s} \cdot N(i) \cdot 2^{-j} .$$

As in the discussion of horizontal resolution we wish to approximate by powers of 2, and determine a $g(j)$ such that

$$f(j) \cong 2^{g(j)} .$$

The video line sampling frequency is then determined at the S-M-V controller from

$$(\Delta Y)_v = 2^{q+n+g(j)-p}$$

since the four terms in the exponent are defined by the parameter assignments.

5. MEDIA SELECTION

Media selection is determined by the parameters F, V and C. The choice of a Read or Write command is then determined from the source-destination matrix shown in Figure 9. Of the sixteen possible states for F, V, C and Read/Write ten are allowed as meaningful or useful, and this may be succinctly stated as:

States	Source		Destination		Command	Figure
4	$(F \oplus V)$	$\cdot$	$(C \oplus \overline{C})$	$\cdot$	READ	15
1	F	$\cdot$	$V \cdot \overline{C}$	$\cdot$	READ	16
1	V	$\cdot$	$F \cdot \overline{C}$	$\cdot$	WRITE	16
4	C	$\cdot$	$(F \oplus \overline{F}) \cdot (V \oplus \overline{V})$	$\cdot$	WRITE	17

where $\oplus$ means exclusive OR. As indicated these states are illustrated in Figures 15-17. A destination medium always exists since the monitor participates in all operations. Whenever core memory (C) is <u>not</u> the image source, display at the monitor or video can be indefinitely repeated by setting the Regeneration parameter, J.

When transferring an image between two media, it is necessary to consider:

a) the X/Y aspect ratios, and

b) the X/Y resolution ratios.

If either of these ratios differ, then a contraction quite independent of any magnification can take place along one of the axes. Both sources of image distortion may be averted by matching <u>aspect ratios of the unit cell</u> at source and destination media. Since several media may be involved it

is useful to adopt the concept of an S-M-V control grid and coordinate system through which any inter-media transfer must pass, as illustrated in Figures 14 through 17. One then forces a match between each medium and the S-M-V control grid. All position and resolution specifications in the parameters can be interpreted as referring to the S-M-V control grid and coordinate system. They must be specified with a particular medium (or media) in mind, however, and must be compatible with its associated characteristics. Scanner and monitor are completely dominated by the S-M-V Controller, hence the unit cell match is easily accomplished. The same is true of core memory as a destination medium. As a source medium the core memory unit cell match is under program control, and it is therefore necessary to associate inviolate unit cell as well as other parameter information with any string representation. Except for initiating a video scan, the link between S-M-V Control and video is basically an information transfer link. The video match is effectively accomplished by selectively transferring information from video (say every other scan line) and by holding back information to video (say blanking every other scan line) by employing $(\Delta Y)_v$ as discussed in the section on Vertical Resolution.

Extending this "match-to-control" concept allows all the transformations (rotation, magnification and translation) discussed in the following sections as well as the dual interpretations of video as a source medium.

The entire transformation discussion is from the point of view of gross resolution. Vernier resolution differs basically in having an inherent magnification of 2^{b_r} to both Monitor and Video, and in having a limited window area.

6. MONITOR TRANSFORMATIONS

Information is communicated to the monitor during each of the S-M-V operations. The area of interest in an image is specified by a 'window' at the S-M-V control grid delineated by the Begin and End Coordinates. Three types of transformations may be applied to the window as viewed at the monitor: rotation, magnification and translation.

6.1 <u>Rotation</u>

The Rotation parameter, G, allows the option of:

R1) slaving the monitor to the S-M-V Controller grid in scan axis and direction or,

R2) choosing the scan axis and direction at the Monitor to be parallel to the X-axis and incrementing irrespective of the Controller choices.

When option R2) is taken then scanning the X-axis at the Controller grid obtains the transformations shown in Figure 10, whereas scanning the Y-axis yields the transformations shown in Figure 11. The choice of a B-E orientation fixes the scan direction and the initial scan line, hence selects one of the four transformations. The four transformations in Figure 10 are called the "four group" of rotational symmetries on the rectangle. The eight transformations in Figures 10 and 11 define the "Klein Rotation Group" of symmetries on the square.

6.2 Magnification

The window displayed at the monitor can be magnified by factors of 2 with the parameter h subject to the combined restrictions:

$$h + \begin{Bmatrix} p \\ q \end{Bmatrix} \leq \begin{Bmatrix} p_{max} \\ q_{max} \end{Bmatrix}$$

The underlying assumption is that the range of resolution options on p and q is identical at monitor and scanner, and that the unit cell at monitor is magnified by $m = 2^h$.

One naturally constrains the choice of h to keep the magnified window from exceeding the raster area:

$$m \cdot \begin{Bmatrix} |XB-XE| \\ |YB-YE| \end{Bmatrix} \leq 1.$$

This restriction is refined in the discussion below on translation.

6.3 Translation

Translation of the window at the monitor may be achieved with the Monitor Displacement Coordinates. As shown in Figure 12, D transforms into (0, 0) at the monitor, hence B is repositioned accordingly.

If a magnification m is superimposed on the translation it affects the area delineated by the D-E coordinates, hence the combined transformation is completely defined as operating on the two vectors $\vec{u}$ and $\vec{v}$:

1) translate the tail of $\vec{u}$ to (0,0) and

2) magnify the length of $\vec{u}$ and of $\vec{v}$ by m.

The four allowed orientations of D, B and E are shown in Figure 13. The implied constraint is that in case (a) $D \leq B \leq E$ with a corresponding interpretation for the other three cases. D always transforms into the corresponding corner position at the monitor with Rotation option R1). For Rotation option R2), D goes to (0, 0) at the monitor in all cases.

For proper centering, one must choose (XD, YD) such that

$$m\ (\ |XB - XE| + 2|XD - XB|\ ) = 1 \text{ and}$$

$$m\ (\ |YB - YE| + 2|YD - YB|\ ) = 1.$$

Complete positioning freedom is not always possible when combined with one of the rotation transformations, e.g., when the window is very close to the edge of the grid and the chosen transformation requires D to be on the edge side of the window.

6.4 Totally Slaved to Scanner

When tracking a line or a boundary, by scanning a sequence of windows, a 1-1 correspondence between Monitor and source is desirable; otherwise the relative positioning of windows at the source is not reflected at the Monitor, and the tracking procedure cannot be viewed. This can of course be achieved with the proper parameter assignments as a standard transformation but one would like to avoid the time involved in doing so. Since the window will be small the scanning time can be significantly reduced by recognizing a special case. The following natural setting for the parameters listed can be interpreted as defining the special case:

1) (XD, YD) = (0, 0), no translation

2) gross resolution

3) no rotation, option R1)

4) no magnification

As shown in Figure 14, the Controller can then avoid the time-consuming redundancy of the transformation steps inherent in a sequence of small windows.

6.5 Totally Slaved to Video

As indicated in Figure 14, video is included in the total slaving concept. For video this is accomplished by replacing constraint 4) in the previous section with the following:

4') $h \cdot \Delta X = \Delta X_{max}(j,n)$.

At most one window can be scanned per video frame, thereby limiting the repetition rate.

7. VIDEO TRANSFORMATIONS

The video network, unlike the monitors, can act both as a source and as a destination. A window, specified by the Begin and End coordinates at the S-M-V control grid, determines the area of interest. Transformations similar to those at the monitor can be effected within the limits of the video constraints.

7.1 Source Medium Options

It is useful to distinguish two interpretations of video as a source medium:

S1) 1-1 correspondence between video and the S-M-V control grid (excluding rotation), thereby allowing translation and magnification of a window to the monitor;

S2) 1-1 correspondence between video and some portion of the S-M-V control grid, effectively allowing translation and <u>de</u>magnification of a window to film.

Options S1) and S2) are illustrated in Figures 15 and 16, respectively.

7.2 Rotation

When video acts as a destination medium, the transformations are effected in the same manner as they are to the monitor under option R2). Because the video scan axis and direction are fixed, option R1) never applies.

When video participates as a source medium the role is reversed and one always gets the inverse transformation to the S-M-V control grid.

If option R2) is chosen for the monitor the two transformations cancel (into and then out from the control grid) — effectively yielding the identity transformation to the monitor.

7.3 Magnification and Demagnification

Equation (6) defines $(\Delta X)_{max}(j,n)$, the largest useable ΔX. Choosing $\Delta X < (\Delta X)_{max}(j,n)$ allows a video magnification of

$$m_v(j,n) = \frac{(\Delta X)_{max}(j,n)}{\Delta X} = 2^{h_v(j,n)}, \text{ so}$$

$$h_v(j,n) = b_g - j + n - p = p_{max}(j,n) - p.$$

When video is a source medium m_v is a demagnification, and when video is a destination medium m_v is a magnification.

In the S1) interpretation of video as a source medium $\Delta X = (\Delta X)_{max}$ is assumed, and the monitor magnification is achieved in the same manner as when the source is core memory or film scanner.

7.4 Translation

When video is a destination medium translation is effected in the same way as it is at the monitor with the rotation option R2); (XD, YD) at the S-M-V control grid transforms into (0, 0) at the video. For proper centering (XD, YD) is chosen so that:

$$m_v(|XB-XE| + 2|XD-XB|) = S(j,n) \,.\, \Delta X \leq 1,$$

$$m_v(|YB-YE| + 2|YD-YB|) = \frac{\Delta Y}{(\Delta Y)_v} \,.\, N_u(i) \leq 1,$$

where $N_u(i)$ is the number of useable lines per video frame (or maximum $(\Delta Y)_v$ steps).

With video as a source medium translation to the monitor is accomplished by associating (0,0) at the video with (0,0) at the S-M-V control grid. Translation to the monitor then takes place in the usual way. This is option S1) and is illustrated in Figure 15. Option S2) is accomplished by associating (0,0) at the video with (XD, YD) at the S-M-V control grid and is illustrated in Figure 16. Translation to film then takes place as the inverse of the translation effected when the transfer is from film to video. Note that translation to monitor and film cannot be effected simultaneously; the options S1) and S2) are mutually exclusive as far as translation is concerned — hence the distinction.

7.5 Totally Slaved as a Destination

Video is not likely to be useful for display under the totally slaved concept, since this would constrain the sampling increment to be

$$\Delta X = \Delta X_{max}(j,n).$$

8. SUMMARY

This paper has developed the parametric description of a general purpose Scan/Display System for image digitization and display. Central to the system is the S-M-V Controller which can service either simultaneously or individually three distinct media: film, closed-circuit television and incrementally-driven CRT displays. An adjunct of the system is a Video Communications Net to provide both high and commercial resolution service to remote users.

8.1 Media Compatibility

The S-M-V Controller acts as a media-media interface that identifies the necessary information transfer constraints or rejects the operation request as one demanding inconsistent parameter assignments. Transfer constraints considered include X/Y resolution ratios, aspect ratios and line sweep times of the media, and D-A/A-D conversion times. A constant data rate option allows operation at I/O channel capacity for all choices of gray scale resolution.

The digital encoding of an image generated in a scanning operation can be retransmitted to the S-M-V Controller for output (display) — and on any of the three available media.

8.2 Rasters

By associating (X,Y) positions with binary counter value pairs the controller can generate a family of the two-dimensional regular lattices - rectangular and hexagonal. X and Y resolutions are independently variable, the allowed resolution values are in geometric progression and correspond to changes in counter incrementing position. A selected "window" of the full image can be specified.

8.3 Sampling/Display Strategies

Three sampling formats (Raster, Coordinate and Incremental) allow a variety of sampling/display strategies. Raster format provides uniform sampling of all lattice positons. For coordinate format however, sampling takes place only at those lattice positions where the image satisfies some criteria prescribed by selection of a triggering/filtering circuit.

Incremental format is provided for segment vector plotting. Commands are provided for setting the starting point, line width and plotting resolution. Segment iteration can be specified.

The sampling beam stencil is variable in size, shape and orientation. The shape options are spot/slit. The slit option includes orientation resolution and range.

8.4 Metrological Facilities

An optional local extension of position resolution can be specified through a gross/vernier counter selection. With the vernier option selected, the gross counters define a benchmark while the vernier counters represent a local displacement. Using this technique, positional resolution of 1:30,000 is currently attainable in flying spot scanning.

8.5 Implementation

The Illiac III computer[9,10] employs a scan/display system with parameters as specified in Appendix C óf this paper.

Except for the video scan converter, the microimage storage and the video storage, the scan/display system is anticipated to be operational by Summer 1969.

9. ACKNOWLEDGEMENT

Many stimulating discussions with members of the Illiac III staff aided in the formulation of concepts developed in this paper. Mr. Robert C. Amendola has contributed significantly to the Video Network specifications and to scanner optical design. Dr. Kenneth J. Breeding participated in the first design of a scanner controller which was subsequently expanded into the S-M-V controller described in this paper.

A description of the analog and digital logic design of the scan/display system is now being prepared for publication by Dr. James L. Divilbiss and Mr. Ronald G. Martin, respectively.

The authors wish to thank Mr. John H. Otten for preparing the illustrations and Mrs. Donna J. Stutz for typing the paper.

APPENDIX A. DEVICE SPECIFICATIONS

Scanners

The scanners are flying spot scanning systems with an added diquadrupole coil for astigmatic defocusing of the spot into a line element to achieve a slit mode. All scanners are capable of either scanning from developed film or photographing onto unexposed film. The optical path of the beam is split, with one path transversing the film and the other path through a reference grid to establish stability against engraved fiducial marks.

Several types of media transports are provided to handle the projected range of problems. A 70 mm. scanner is provided primarily for 70 mm. negative bubble chamber film. Here the format of the raster is 2.362 inches x 3.522 inches, and the minimum spot size is approximately 0.001 inch at the film. Due to the length of the frame to be scanned, scanning is done in two steps. The two horizontal halves of the frame are scanned successively with a 4 mm. overlap to establish half-frame continuity. Large motors are used for slew and gross positioning of the film and a small digital stepper motor is used for fine positioning of the frame. Frame position sensing is accomplished by using the digital stepper motor as a tachometer and by counting sprocket holes. Total film capacity is 1000 feet.

A scanner for handling 47 mm. film is similar to the 70 mm. transport design except for the following:

The film format is different. A friction drive is used on the digital stepper motor, since the film is unsprocketed. The frame position is determined by sensing small index blocks at the lower edge of the film using a fibre-optics light guide and a photodiode.

The microform scanner contains three units. The first is a 35 mm. full frame digitally controlled camera which can read light through the film both negative and positive. The second unit contains a 16 mm. Bolex camera for making computer-generated black and white movies and a modified 16 mm. film editor for scanning 16 mm. film of all types. The third unit is a microfiche transport mechanism for scanning and producing a single microfiche in the 72 image COSATI format. For the three different units the C.R.T. raster is adjusted optically to fit the particular frame size.

A fourth type of scanner is built around a microscope with a digitally controlled automatic stage. Positional accuracies are on the order of $\pm$ 2 microns, and the maximum slide area coverage is 1.2 inches x 1.2 inches. Variable reduction is available from a four objective rotating turret. Full visual observation is available to an operator.

Monitors

The monitors consist of 21 inch cathode ray tubes controlled in a manner similar to the scanner C.R.T.'s; viz., digital position counters control the spot location through accurate, high-speed digital-to-analog converters. The monitor counters are digitally controlled directly from the S-M-V Controller via an incremental communications scheme; essentially the only commands issued by the S-M-V Controller for the monitors are increment the counters, decrement the counters, reset the counters, and reset the parameters. Therefore, any spot movement possible on a scanner C.R.T. can be accomplished on the monitor C.R.T. The video input for the C.R.T. grid is also synchronized by the S-M-V controller.

Included with the monitors for communications to a central processing system are a selectric typewriter, microtape input/output tape drives, and a light pen for cursor control.

Video Scan Converter

The video scan converter consists of a high resolution storage tube capable of storing a useable picture for at least 30 seconds. Multiple readouts can be made from a stored image before degradation is significant.

The storage tube can be written into and read from at any of the video rates in the system (525, 1536F, 1536S) on the video switching matrix side. On the SMV control side the scan converter looks like a film as seen by a scanner; therefore, reading and writing is handled in exactly the same manner as it is in a scanner.

Video Switching Matrix

The video switching matrix is a mechanical cross bar matrix. Therefore, the switching speed will be in the order of 100 milliseconds or less. In this routing switch any source can be switched to from one to three different destinations simultaneously. In addition, switching provisions are also included to mix any two video sources to provide a composite signal to the selected destinations.

Character Generator

The Character Generator is designed to accept up to 512 ASCII characters into its 4096 bit memory. A 99 dot matrix, 9 dots wide by 11 dots high, is used to develop each character into the appropriate video levels. The maximum TV screen display is 16 horizontal rows of 32 characters or spaces each. Alternatively 132 characters/line printout can be generated on the Videograph printer. A special cursor is also available along with eight commands for controlling it.

The output composite video signal can be either 525 or 1536 lines per frame, depending upon the externally supplied sync signal.

Videograph Printer

The Videograph Printer can print on demand at a rate of 0.8 seconds per 8-1/2 x 11 inch sheet. Horizontal resolution is 128 lines per inch and vertical resolution matches the high resolution of the 1536 line slow CCTV cameras. Gray scale resolution is limited to four shades. The paper used is inexpensive zinc-oxide coated stock.

525 Line T.V. Cameras and Monitors

The 525 T.V. Cameras and Monitors are conventional television units; namely, 525 lines per frame, 30 frames per second interlaced (60 fields per second). These units provide for relatively low cost reduced resolution, which is sufficient for many message routing and simple acquisition and display purposes.

1536 F/S Cameras

The 1536 F/S cameras are vidicon camera units which can be remotely selected to operate either in fast scan mode (15 frames per second) or slow scan mode (1.25 frames per second). The format of either mode is 1536 lines per frame done in a sequential (non-interlace) scan. The aspect ratio is variable, but it is set for a nominal 8-1/2 x 11 aspect ratio. The camera bandwidth is limited to 9.5 Mhz for fast scan and 1.4 Mhz for slow scan.

Remote Video Consoles

Each remote console is a self-contained unit with two video monitors and the necessary equipment for communicating with a digital computer. The video monitors consist of a 17 inch 1536 lines per frame slow (1.25 frames per second) monitor with a P-26 phosphor and a 17 inch 1536 lines per frame fast (15 frames per second) monitor with a VC-4 phosphor. Each monitor matches characteristics of the associated camera.

Included with the console for direct digital communications to the central computer are a teletype ASR-33 unit and a small special keyboard to be used for entering frequently used machine orders. Other items to be included with the consoles are a microfiche reader, a digital patch panel for digital control signals, and an analog patch panel for analog control signals.

Special plug-in options for a universal cursor control could provide for such devices as a light pen, joy stick, matrix pad, bug, etc. Other options could include provisions for direct handwriting of orders at the console by T.V. camera pick-up and/or Rand tablet type device and a monitor microfiche camera for filming images from the C.R.T. screen.

Microimage Storage

The Microimage Storage consists of a microfiche reader/access mechanism that is able to store, retrieve, and display COSATI standard microfiche on demand. Storage of the microfiche is by a rotary drum that is a changeable unit. Images can be digitally selected, and the display of any requested image requires less than five seconds. Access time to an adjacent image (i.e., one within the same fiche) is less than two seconds. The output is displayed in an 8-1/2 x 11 inch format if desired, and it is projected upon the two inch vidicon of a 1536 F/S line television camera for distribution into the video network.

The drum holds 750 modified microfiche cards of 60 frames each. Each frame again contains an array of 72 microimages or basically a standard microfiche. Therefore, a single drum will provide storage for 3,240,000 page images. Readout from the selected microfiche frame is accomplished with a fly's eye readout mechanism.

Video Storage

The video storage consists of an interchangeable 72 track video disk, where a single track can contain a complete image. Input and output can be at either the 1.25 or the 15 frames per second rate with resolution matched to the corresponding video devices.

APPENDIX B
SYMBOL AND PARAMETER LIST

$		Parameter values assigned at design time
*		Parameter values explicitly assigned at execution time

Upper Case Latin

*	A	Scan Axis selection
	ACW	Angle Coordinate Word
	B	Equivalent to (XB, YB)
*	B_s	Standard spot/nonstandard spot, or slit selection
	BCW	Begin Coordinate Word
*	C	Media selection, Core memory
	D	Equivalent to (XD, YD)
	DCW	Display Coordinate Word
*	DF	Data Format selection
	DPB	Display Parameters Byte
	DX	X-component of the incremental format Displacement vector
	DY	Y-component of the incremental format Displacement vector
	E	Equivalent to (XE, YE)
	E_v	Same as E, to distinguish Vernier
	ECW	End Coordinate Word
*	F	Media selection, Film (scanner)
	FPB	Format Parameters Byte
*	G	Group rotation selection for the monitor
*	J	Display regeneration request
*	K	Constant data/sample rate option (for a given p) with the raster format
*	L	Lattice selection
	L_s	Length of Slit = 2^v gross basic cells
	LPB	Lattice Parameters Byte
$	N(i)	Number of lines per video frame
	$N_u(i)$	Number of useable lines per video frame (or maximum $(\Delta Y)_v$ steps).

	N_b	Number of Bits in a raster string representation
	N_s	Number of Samples in a raster string representation
	NGL	Number of Gray Scale Levels = 2^{2^n}
	PW	Parameter Word
*	R	Gross/vernier Resolution selection
*	S	Sequence selection, sequential/interlaced
	S(j,n)	Maximum achievable number of Samples per full video scan line
	$S_{max}(j)$	Maximum value of S(j,n) (achieved for n = 0)
	SPB	Slit/spot Parameters Byte
	SX	Sign of DX
	SY	Sign of DY
*	T	Trigger (filter) selection for encoding in the coordinate string representation
*	V	Media selection, Video
	V_s	Sweep Velocity
	W_s	Width of Slit or spot diameter = 4^u gross basic cells
*	XB	X-coordinate, Begin cell
*	XD	X-coordinate, Displacement
*	XE	X-coordinate, End cell
	XE_v	Same as XE, to distinguish Vernier
*	YB	Y-coordinate, Begin cell
*	YD	Y-coordinate, Displacement
*	YE	Y-coordinate, End cell
	YE_v	Same as YE, to distinguish Vernier

Lower Case Latin

$	b_a	Number of bits in the angle orientation counter
$	b_c	Number of interpolation bits concatenated with the b_g -p gross resolution bits
$	b_g	Number of bits in the gross position counter
$	b_o	Number of gross-vernier overlap bits
$	b_r	Number of vernier bits that extend gross resolution
$	b_v	Number of bits in the vernier position counter
	c_1	Sweep velocity constant (with $c_1 = f_c$, V_s is given in basic cells per microsecond)
$	f_b	Maximum data bit transfer rate
$	f_c	Position counter incrementing frequency
	$f(j)$	Video unit cell match function = $\frac{r_v}{r_s} \cdot N(i) \cdot 2^{-j}$
	$g(j)$	Video line selection modifier. Closest integer such that $f(j) \simeq 2^{g(j)}$
*	h	Monitor magnification = 2^h
$	h_{max}	Maximum value of h
	$h_{v(j,n)}$	Video magnification/demagnification exponent (see $m_v(j,n)$)
	i	Video system identification
	j	Video system resolution parameter, $S_{max(j)} = 2^j$
	k	$k(R)$: k = 0 for gross b_r for vernier
	m	Monitor magnification = 2^h
	$m_{v(j,n)}$	Video magnification/demagnification = $2^{h_v(j,n)}$
*	n	2^n is the number of bits of gray scale
$	n_{max}	Maximum value of n

*	p	$\Delta X = 2^p$ (see ΔX)
	$p_{max}(j,n)$	Maximum value of p for Video Network = $b_g - j + n$
*	q	$\Delta Y = 2^q$ (see ΔY)
$	r_s	Aspect ratio, control grid (<u>St</u>andard)
$	r_v	Aspect ratio, video
*	s_v	Sign bit of vernier counter
*	u	Slit width is 4^u gross basic cells
$	u_{max}	Maximum value of u
*	v	Slit length is 2^v gross basic cells
$	v_{max}	Maximum value of v
*	z	$\Theta = 2^{z-b_a}$ (see $\Delta\Theta$)
$	z_{max}	Maximum value of z

Greek

ΔC	Counter increment along the scan axis in basic cells
$\Delta t(i)$	Time to sweep one video scan line
ΔX	Sampling increment along the X-axis at the S-M-V control grid ($\Delta X = 2^p$)
$(\Delta X)_{max}(j,n)$	Maximum value of ΔX corresponding to $S(j,n)$
ΔY	Sampling increment along the Y-axis at the S-M-V control grid ($\Delta Y = 2^q$)
$(\Delta Y)_v$	Sampling increment along the Y-axis at video (every $(\Delta Y)_v$ lines)
$\Delta\Theta$	Orientation sampling ($\Delta\Theta = 2^{z-b_a}$ units of angle)
$\delta\vec{x}$	X-axis unit vector
$\delta\vec{y}$	Y-axis unit vector
* ΘB	Orientation Begin value
* ΘE	Orientation End value

APPENDIX C
DESIGN VALUES FOR THE ILLIAC III SCAN-DISPLAY SYSTEM

b_a	angle orientation counter	8 bits
b_c	interpolation bits concatenated to gross	3 bits
b_g	gross position counter	12 bits
b_o	gross-vernier overlap	4 bits
b_r	vernier resolution extension to gross	3 bits
b_v	vernier position counter	7 bits
f_b	maximum data transfer rate	10 Mhz
f_c	counter incrementing frequency	1.25 Mhz
h_{max}	2^h is image magnification at monitor	7
n_{max}	$2^{n_{max}}$ is maximum bits of gray scale	3
p_{max}	X-axis sample increment is 2^p basic cells	7
q_{max}	Y-axis sample increment is 2^q basic cells	7
r_s	Aspect ratio, control grid	1:1 (but variable)
r_v	Aspect ratio, Video	3:4
u_{max}	slit width is 4^u basic cells	3
v_{max}	slit length is 2^v basic cells	7
z_{max}	angle increment is 2^{z-b_a} units	7

References

1. L A DUNN L N GOYAL B H MCCORMICK V G TARESKI
S-M-V programming manual
Department of Computer Science University of Illinois Urbana Illinois, March 1968

2. D M COSTIGAN
Resolution considerations affecting the electrical transmission of technical documents by scanning process
National Microfilm Association Journal Volume 1 Number 3, Spring 1968.

3. B F WADSWORTH
PEPR - a hardware description
Emerging Concepts in Computer Graphics Don Secrest and Jurg Nievergelt (Eds) W A Benjamin Inc New York, 1968

4. ROBERT CLARK W F MILLER
Computer-based data analysis systems
Methods in Computational Physics Volume 5 Berni Adler Sidney Fernbach Manuel Rotenberg (Eds) Academic Press New York, 1966

5. ROBERT B MARR GEORGE RABINOWITZ
A software approach to the automatic scanning of digitized bubble chamber photographs
Methods in Computational Physics Volume 5 Berni Adler Sidney Fernbach Manuel Rotenberg (Eds) Academic Press New York, 1966

6. J VANDER LANS J L PELLEGRIN H J SLETTENHAAR
The hummingbird film digitizer system
SLAC Report Number 82 Stanford Linear Accelerator Center Stanford University Stanford California, March 1968

7. R S LEDLEY L S ROTOLO T J GOLAB J D JACOBEN M D GINSBERG J B WILSON
FIDAC: film input to digital automatic computer and associated syntax-directed pattern recognition programming system
Optical and Electro-optical Information Processing Teppep J Berkowitz D Clapp L Koester C and Vanderburgh Jr A (Eds) MIT Press Cambridge Massachusetts 1965, Chapter 33

8. H KAZMIERCZACK F HOLDERMANN
The karlsruhe system for automatic photointerpretation
Pictorial Pattern Recognition G C Cheng R S Ledley Donald K Pollock and A Rosenfeld (Eds) Thompson Book Company Washington D C, 1968

9. B H MCCORMICK
<u>Advances in the development of image processing hardware</u>
Image Processing in Biological Science Ramsey D M (Ed)
University of California Press, 1968 in press

10. B H MCCORMICK
<u>The illinois pattern recognition computer - illiac III</u>
IEEE Transactions on Electronic Computers Volume EC-12
Number 5, December 1963

FIGURE CAPTIONS

Fig. 1 Block diagram of the Scan/Display System. Note that the Video Scan Converter can be bypassed under program control.

Fig. 2 Segment vector plotting. Note change in stencil size at P and change in resolution (unit cell) at Q.

Fig. 3 Maximum vernier window area with respect to B coordinate. Shown is an overlap of two bits (b_o) and maximum local resolution for a resolution extension of two bits (b_r).

Fig. 4 Slit/Spot geometry.

Fig. 5 Sequential scan along X-axis using a rectangular lattice. ($\Delta Y = \Delta X$).

Fig. 6 Interlaced scan along X-axis using a rectangular lattice. ($\Delta Y = \Delta X$).

Fig. 7 Sequential scan along (a) X-axis, and (b) Y-axis using a hexagonal lattice. The hexagons around point 11 in (a) and point 17 in (b) illustrate neighbor points. The dotted rectangles show neighbor points in the corresponding rectangular lattice. ($\Delta Y = \Delta X$).

Fig. 8 Same as Fig. 7 (a) with $\Delta Y = 2\Delta X$.

Fig. 9 Command matrix. Read/Write selection as a function of selected media and desired transfer direction.

Fig. 10 Group transformations effected by the four different Begin-End coordinate orientations with X-axis scan. (G = 1).

Fig. 11 Same as Fig. 10 with Y-axis scan. (G = 1).

Fig. 12 Image translation and magnification at the monitor.

Fig. 13 Four allowed orientations of D, B and E coordinates with the corresponding monitor interpretation. (G = 0).

Fig. 14 Monitor totally slaved to the source media.

Fig. 15 Magnifying a window at the monitor and/or transmitting to core memory.

Fig. 16 Transmitting between scanner and video. Display at the monitor with $h = h_v$.

Fig. 17 Transmitting from core memory to one or more media. If to video, $h = h_v$.

Fig. 18 Parameter and coordinate words formats as defined for Illiac III.

Fig. 19 Display (a), Lattice (b), Format (c), and Slit/Spot (d) Parameter Bytes as defined for Illiac III.

Table I Inherent characteristics of three video systems and maximum sampling resolution, $S_{max}(j)$, as constrained by other media.

Table II Maximum sampling resolution and interdependence of position and gray scale resolution as constrained by media characteristics. The main entry is the maximum number of samples per video scan line, $S(j,n)$, and the value in parenthesis is the corresponding maximum value of ΔX, $(\Delta X)_{max}(j,n)$.

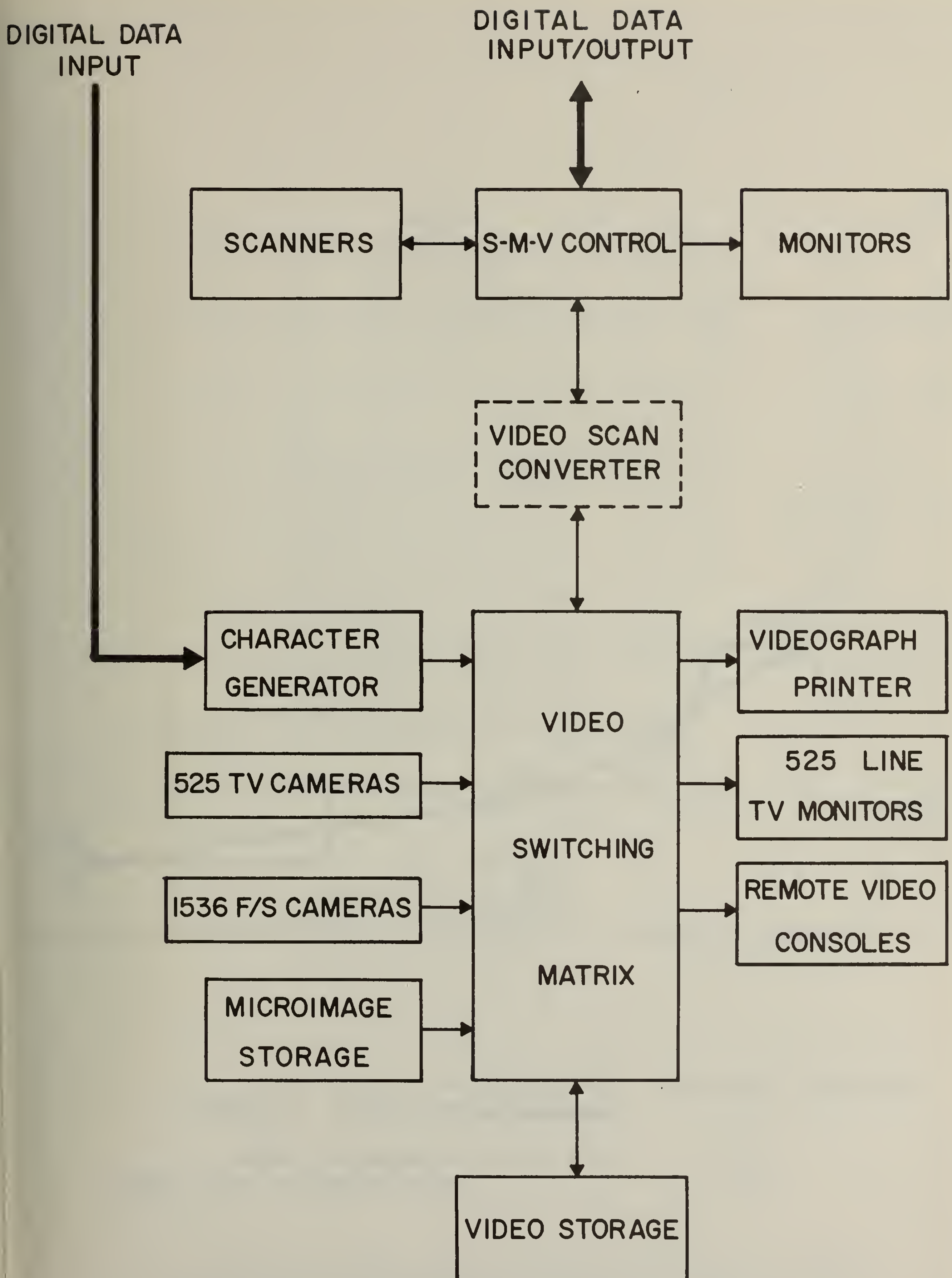


Figure 1 - Block Diagram of the Scan/Display System. Note that the Video Scan Converter can be bypassed under program control.

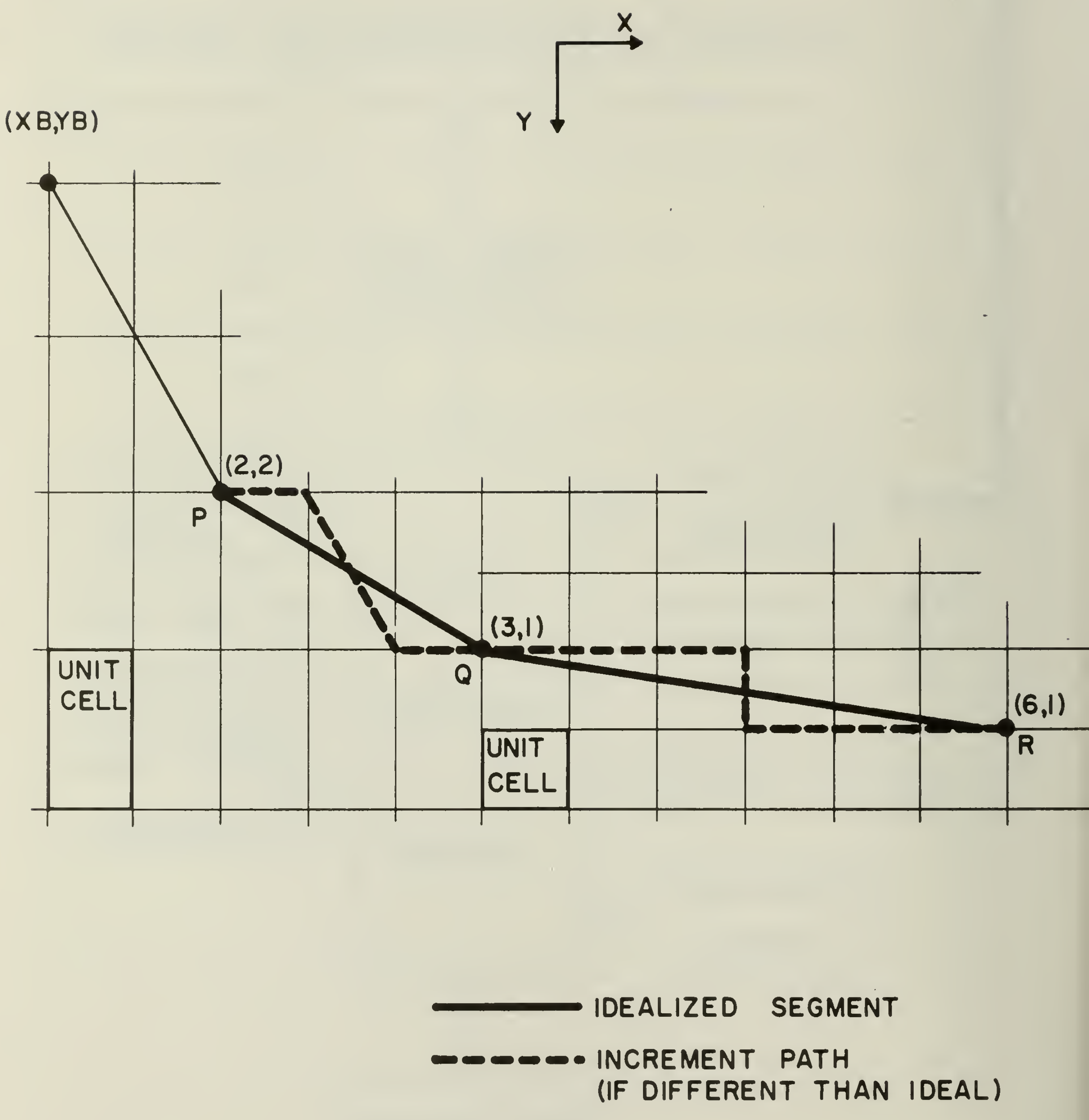


Figure 2 - Segment Vector Plotting. Note change in stencil size at P and change in Resolution (unit cell) at Q.

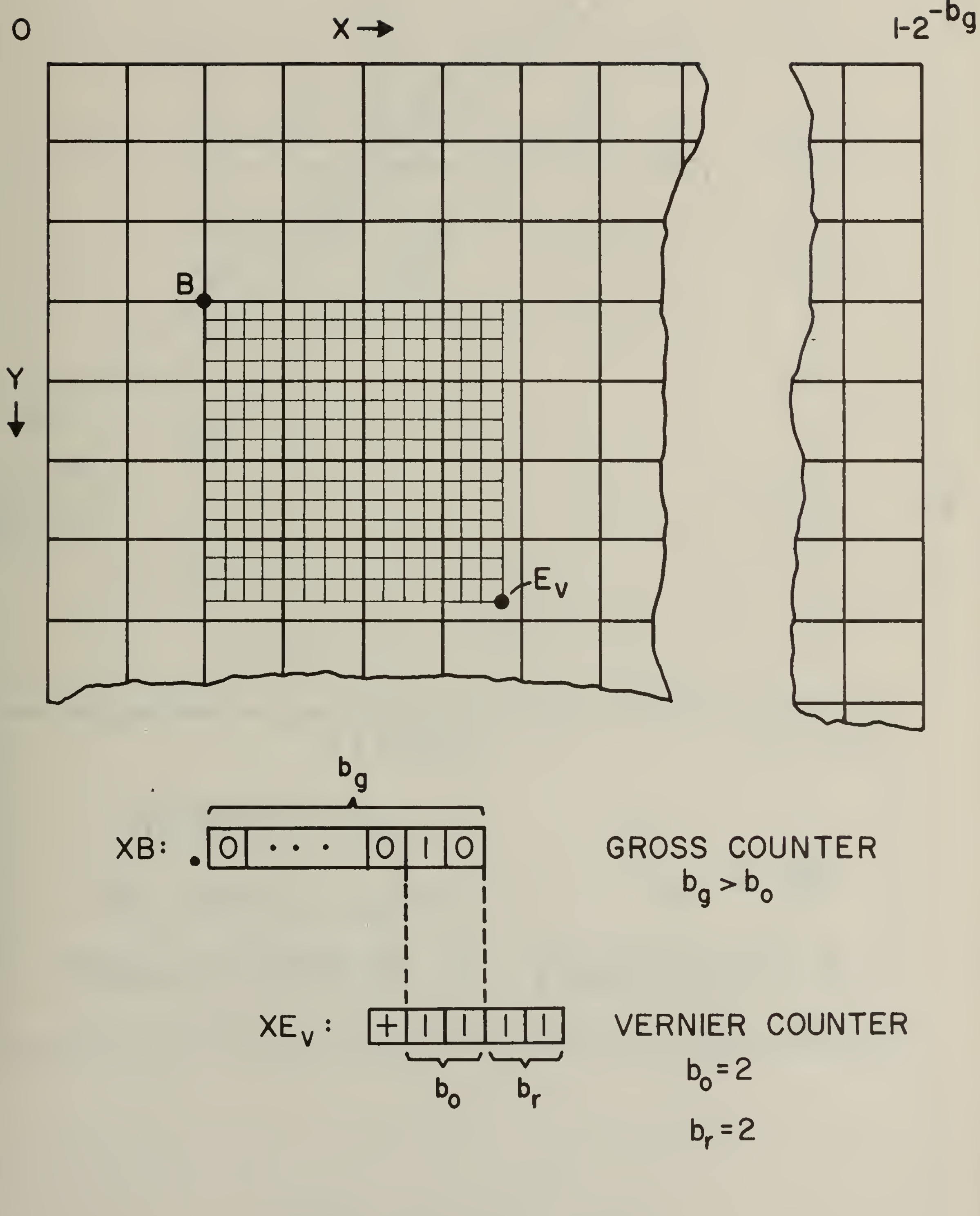
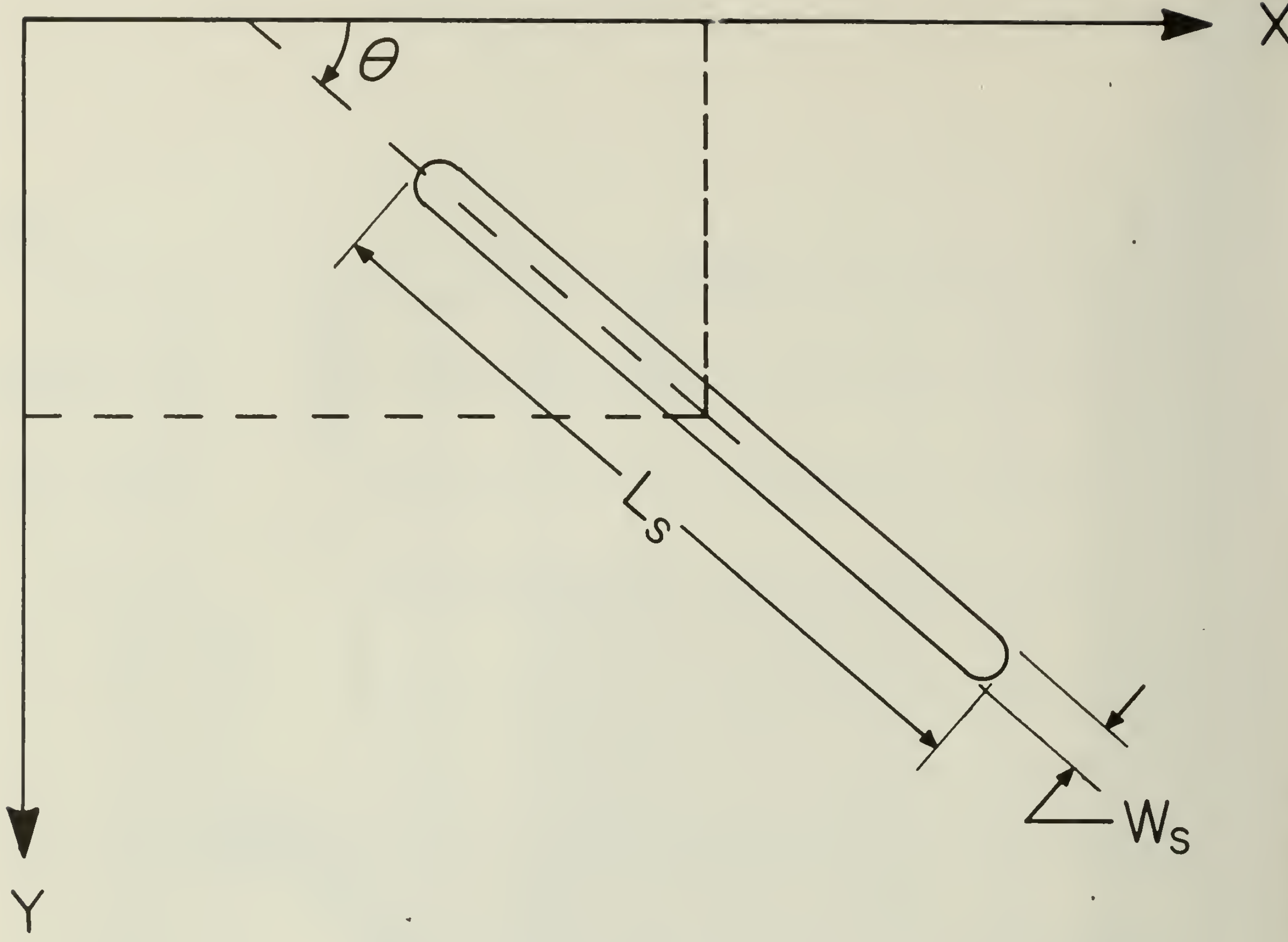


Figure 3 - Maximum Vernier Window Area With Respect to B Coordinate. Shown is an overlap of two bits (b_o) and maximum local resolution for a resolution extension of two bits (b_r).



SLIT:	SPOT:
	L_S = MINIMUM
$W_S < L_S$,	W_S = DIAMETER
θ RELEVANT	θ IRRELEVANT

Figure 4 - Slit/Spot Geometry

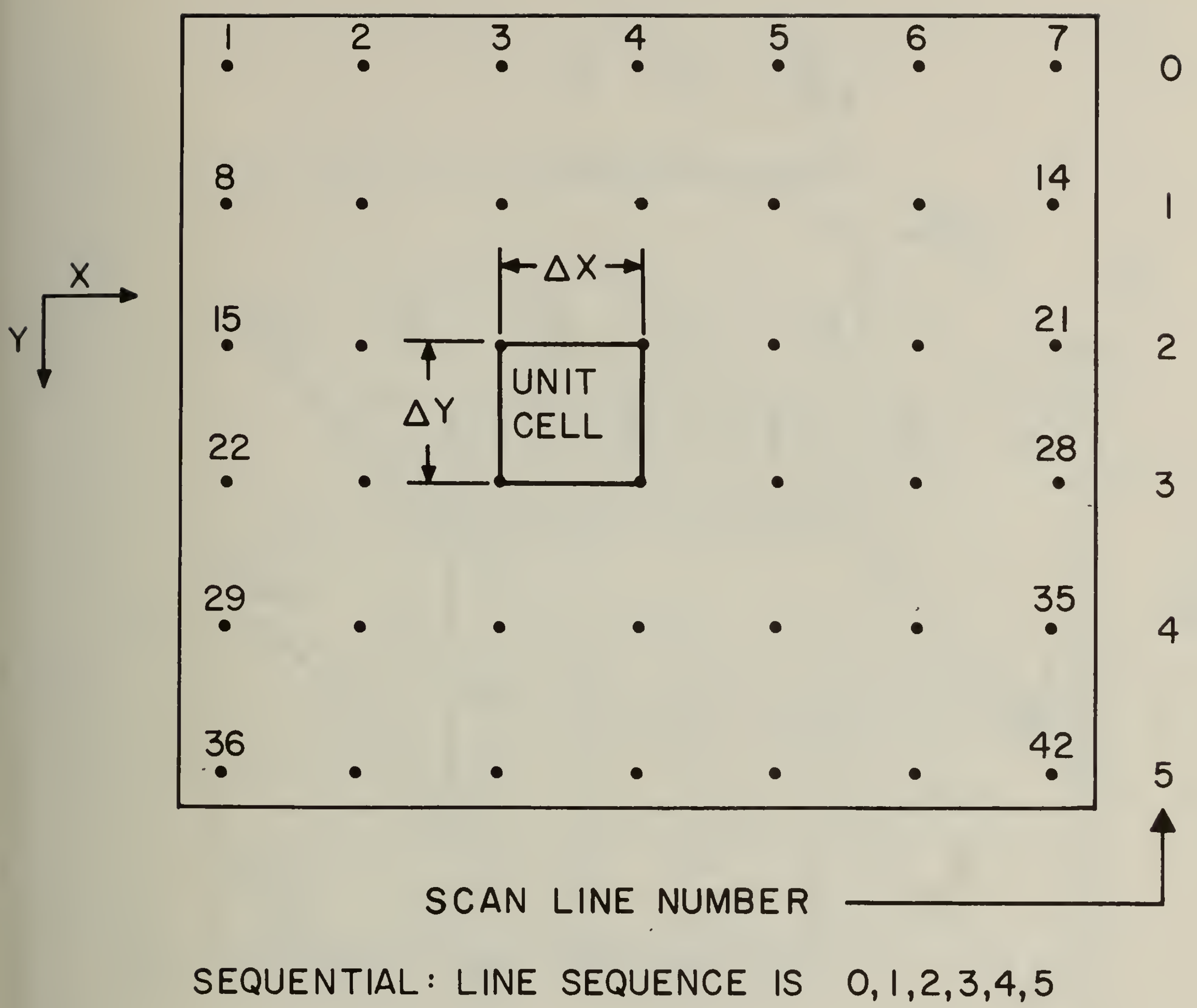


Figure 5 - Sequential Scan Along X-Axis Using a Rectangular Lattice ($\Delta Y = \Delta X$)

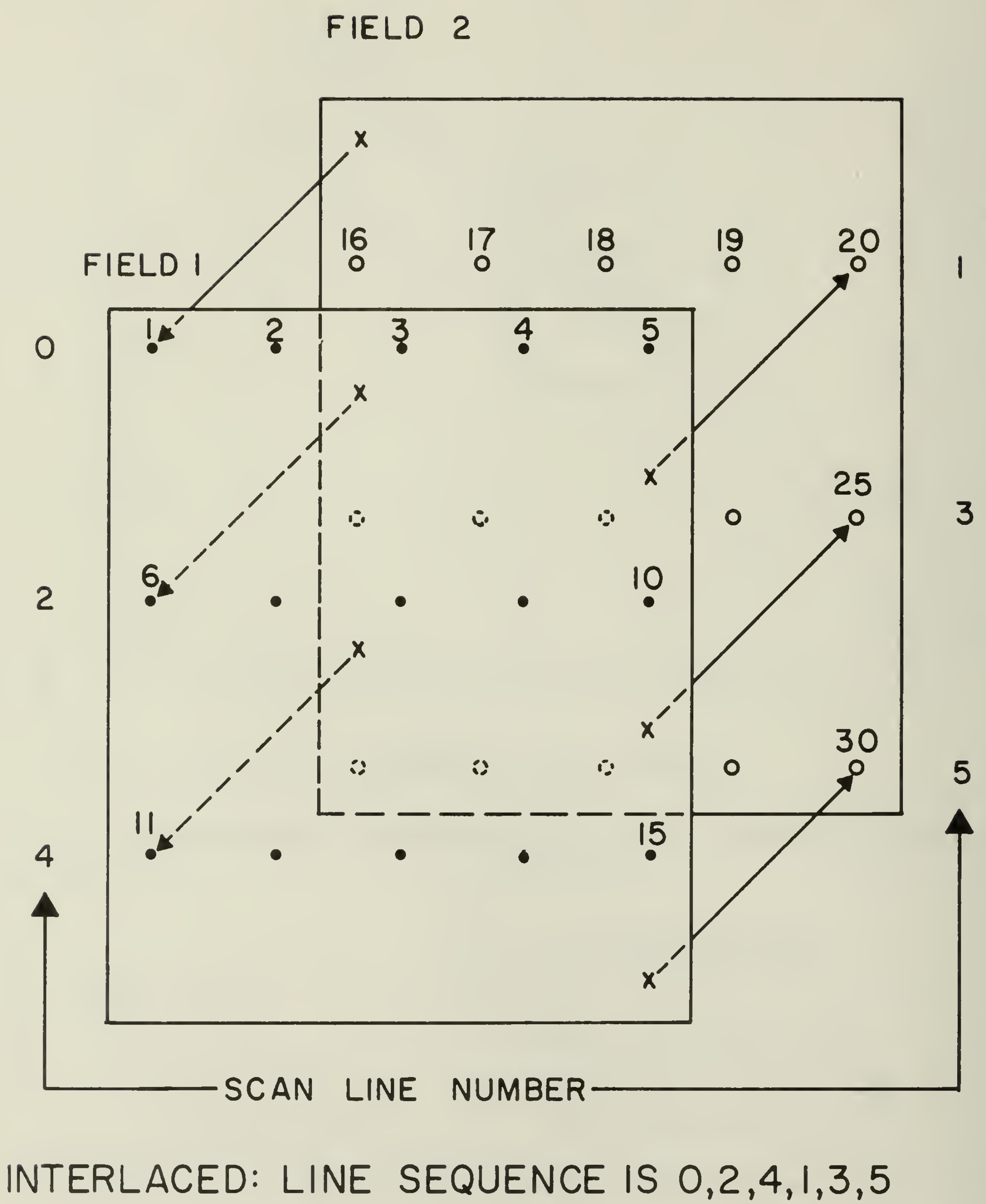


Figure 6 - Interlaced Scan along X-Axis Using a Rectangular Lattice. ($\Delta Y = \Delta X$).

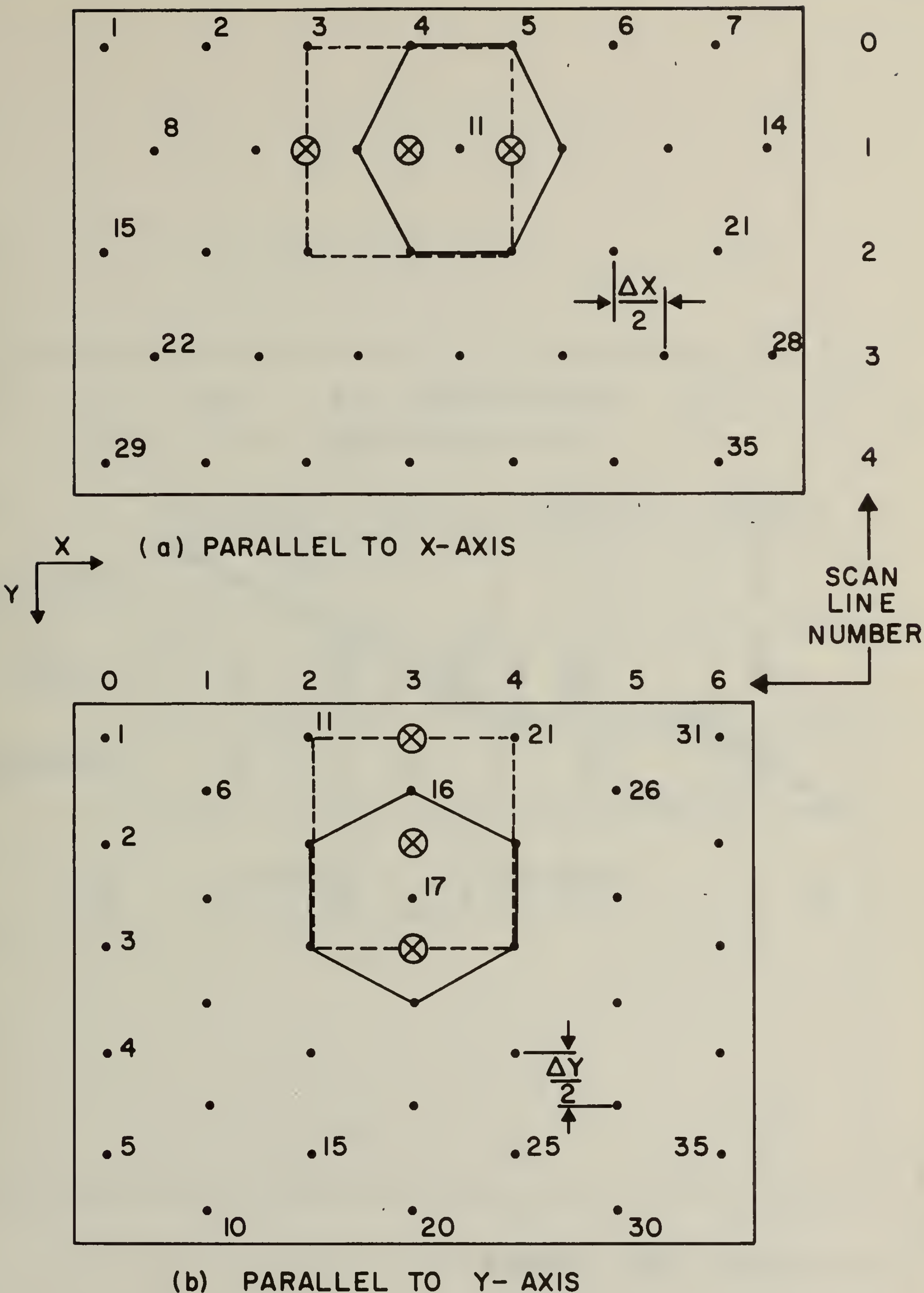


Figure 7 - Sequential Scan along (a) X-Axis Using a Hexagonal Lattice. The hexagons around point 11 in (a) and point 17 in (b) illustrate neighbor points. The dotted rectangles show neighbor points in the corresponding rectangular lattice. $(\Delta Y = \Delta X)$.

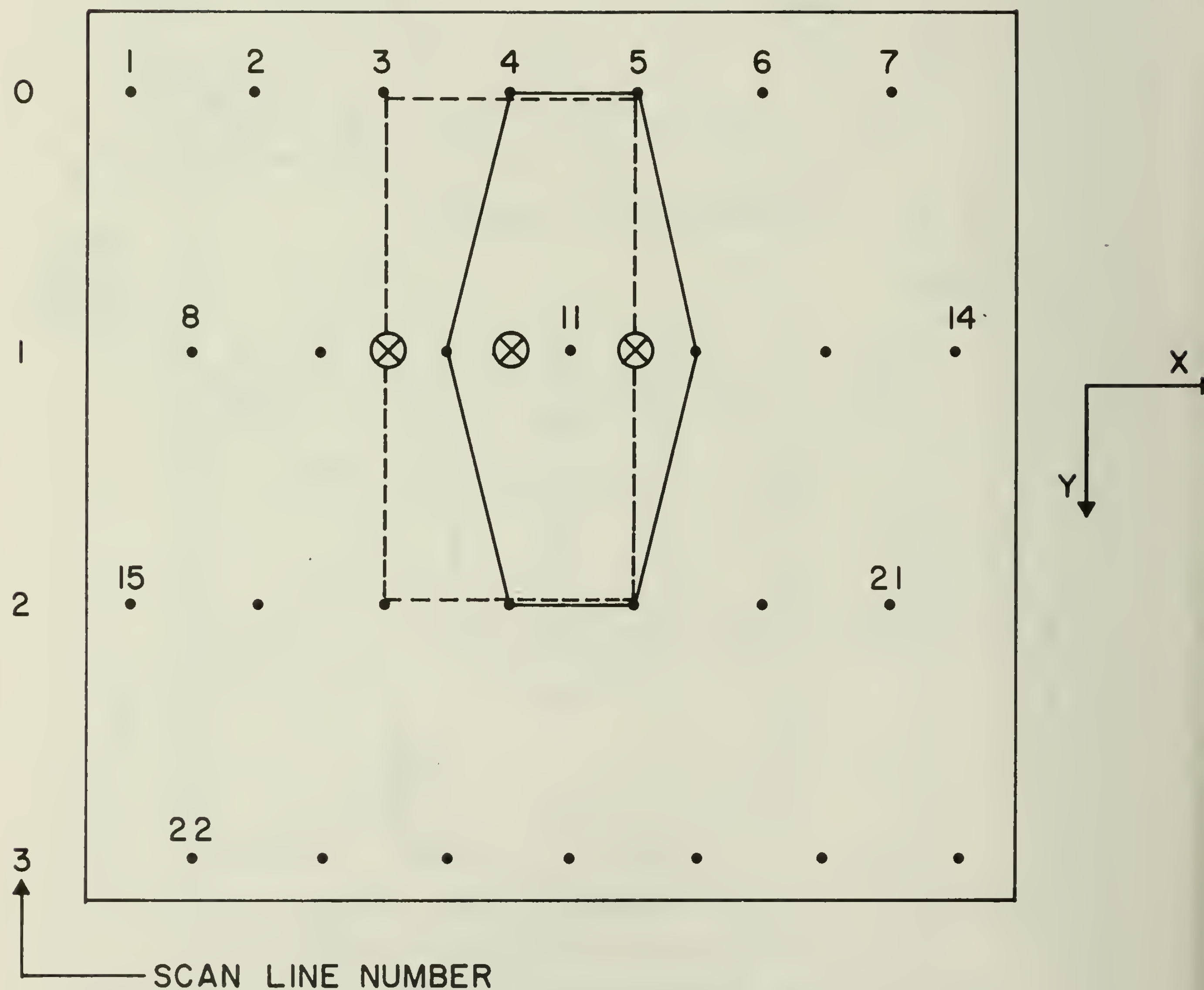


Figure 8 - Same as Figure 7 (a) with $\Delta Y = 2\Delta X$

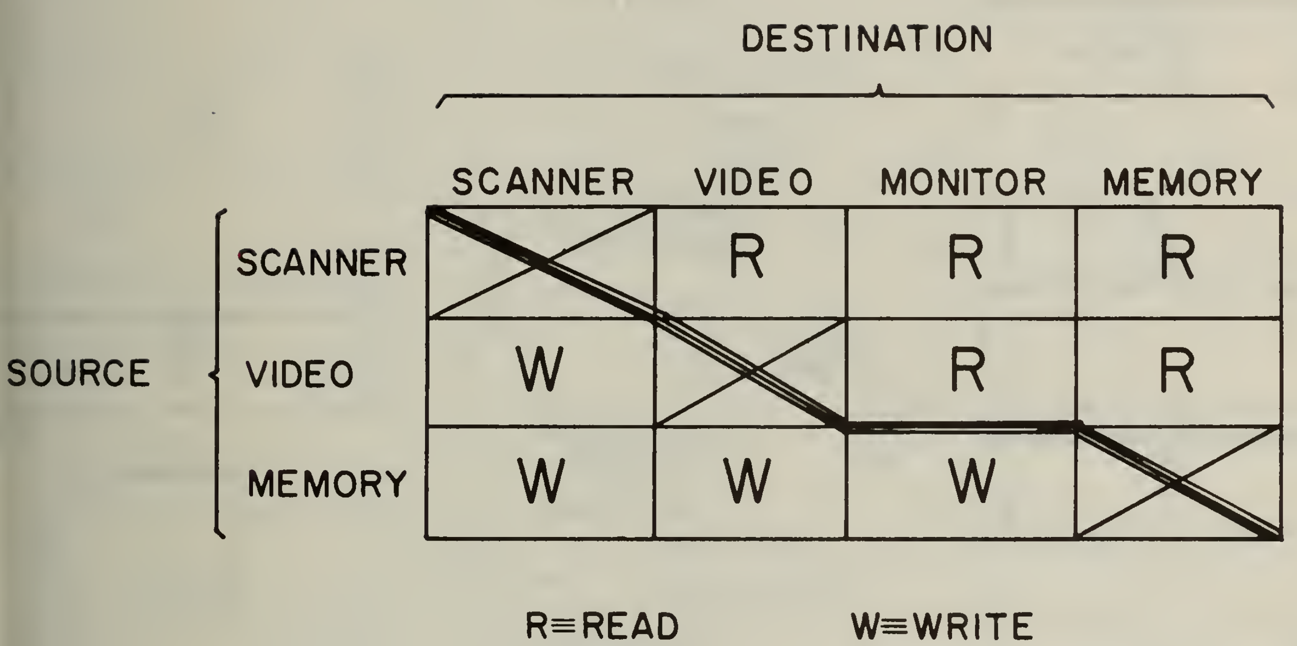


Figure 9 - Command Matrix. Read/Write selection as a function of selected media and desired transfer direction.

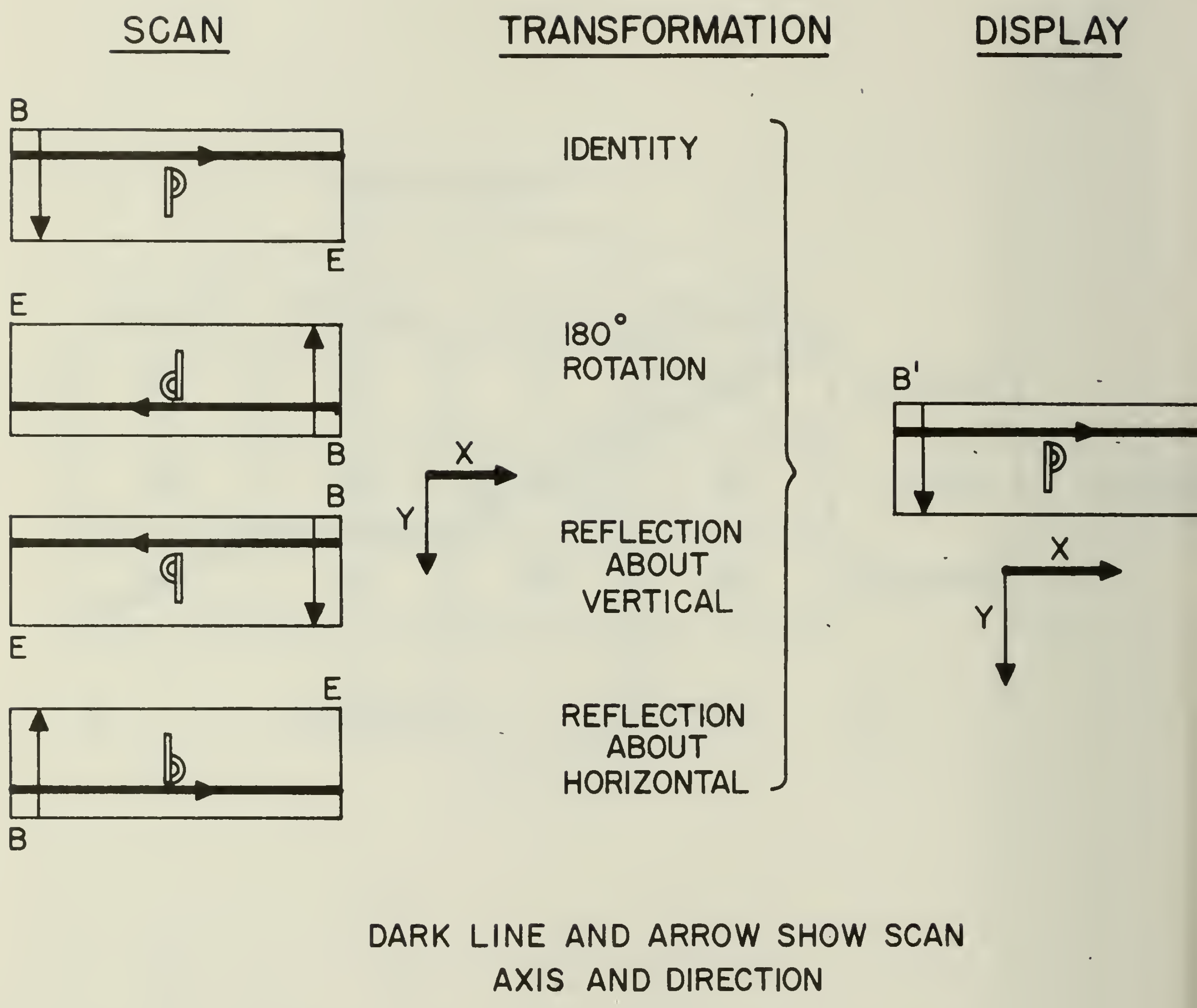


Figure 10 - Group Transformations Effected by the Four Different Begin-End Coordinate Orientations with X-Axis Scan (G = 1)

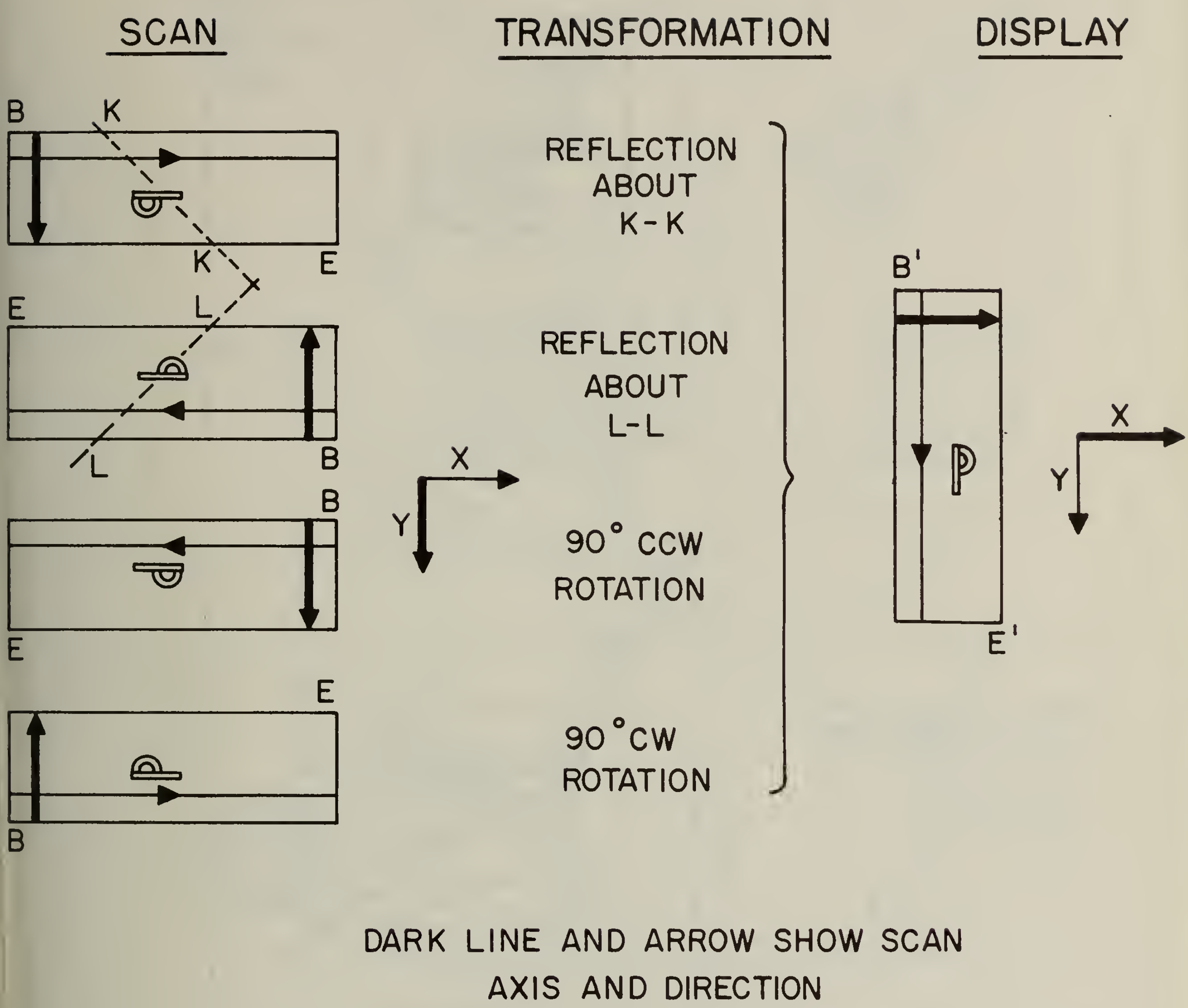
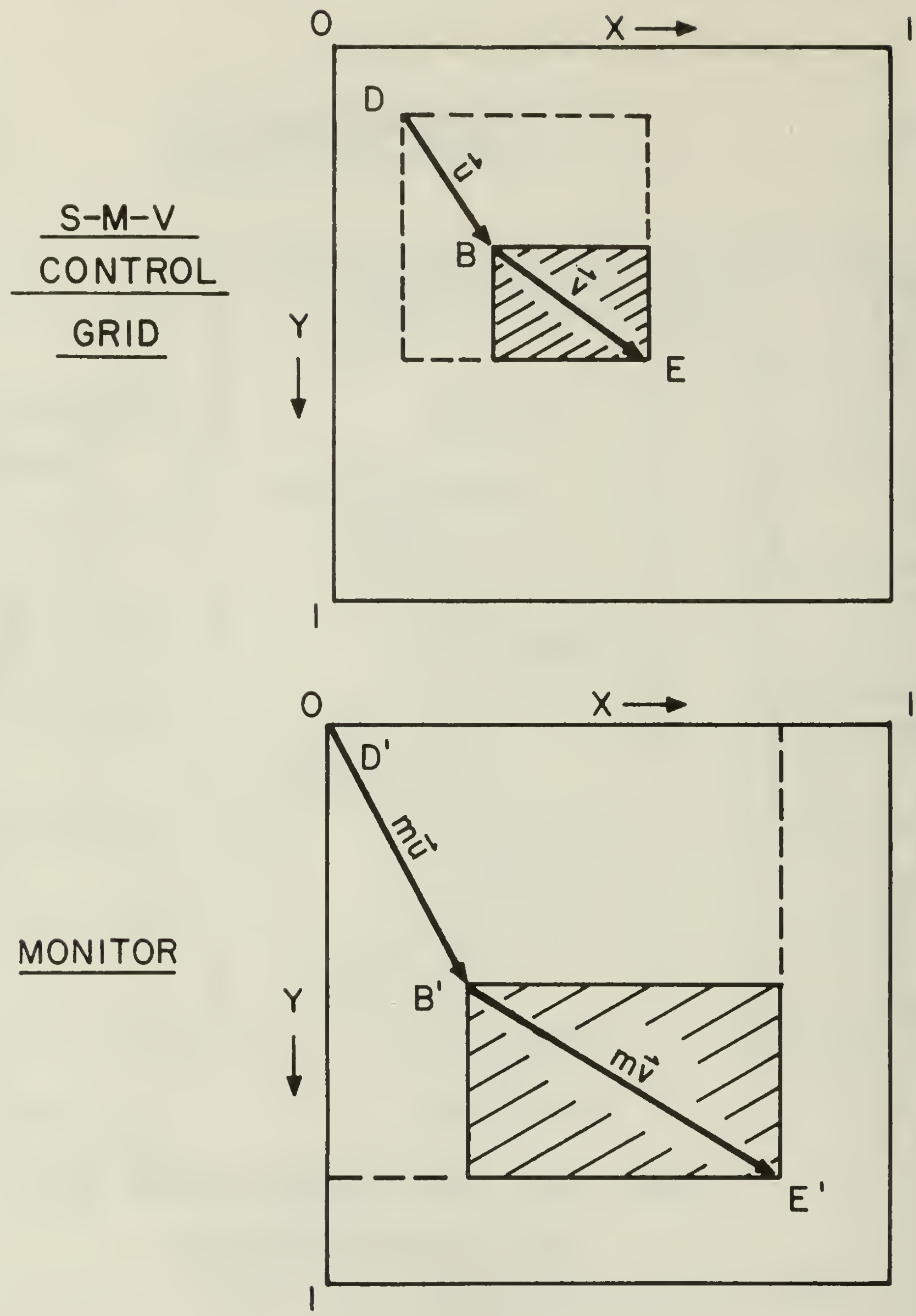


Figure 11 - Same as Figure 10 with Y-Axis Scan (G = 1)



D	≡	DISPLACEMENT	COORDINATES
B	≡	BEGIN	COORDINATES
E	≡	END	COORDINATES
m	≡	MONITOR MAGNIFICATION	

Figure 12 - Image Translation and Magnification at the Monitor

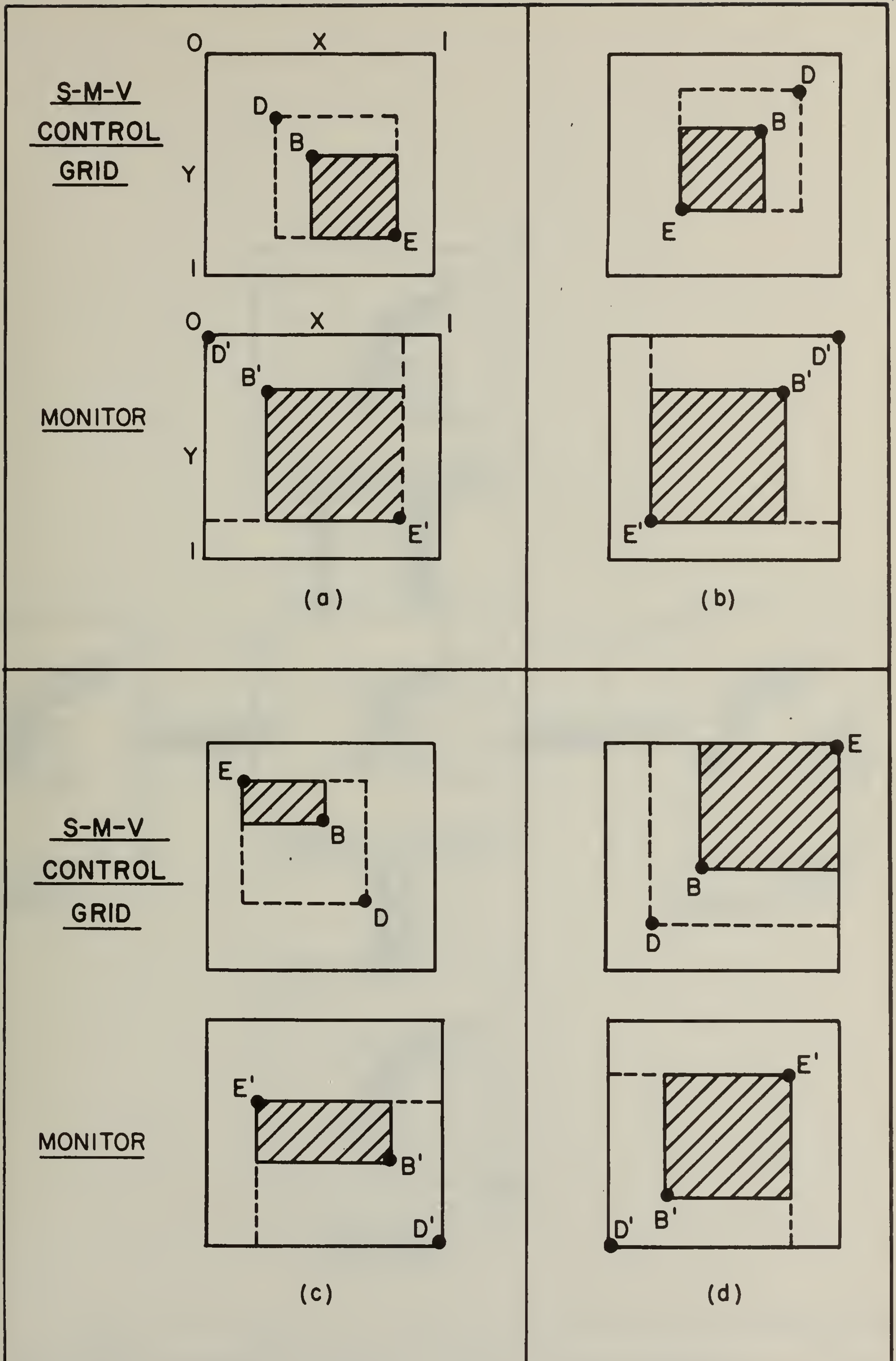


Figure 13 - Four Allowed Orientations of D, B and E Coordinates with the Corresponding Monitor Interpretation (G = 0)

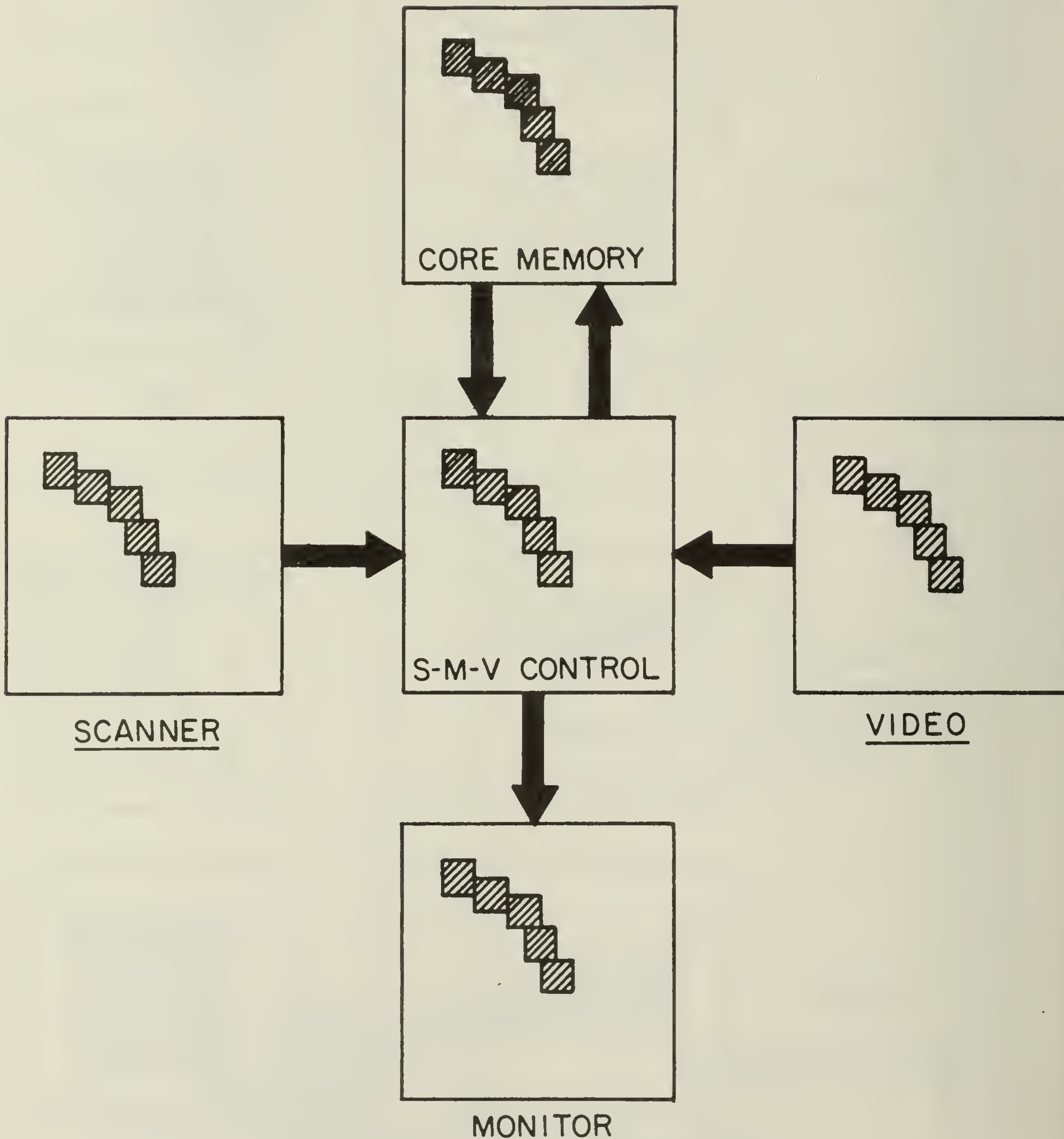


Figure 14 - Monitor Totally Slaved to the Source Media

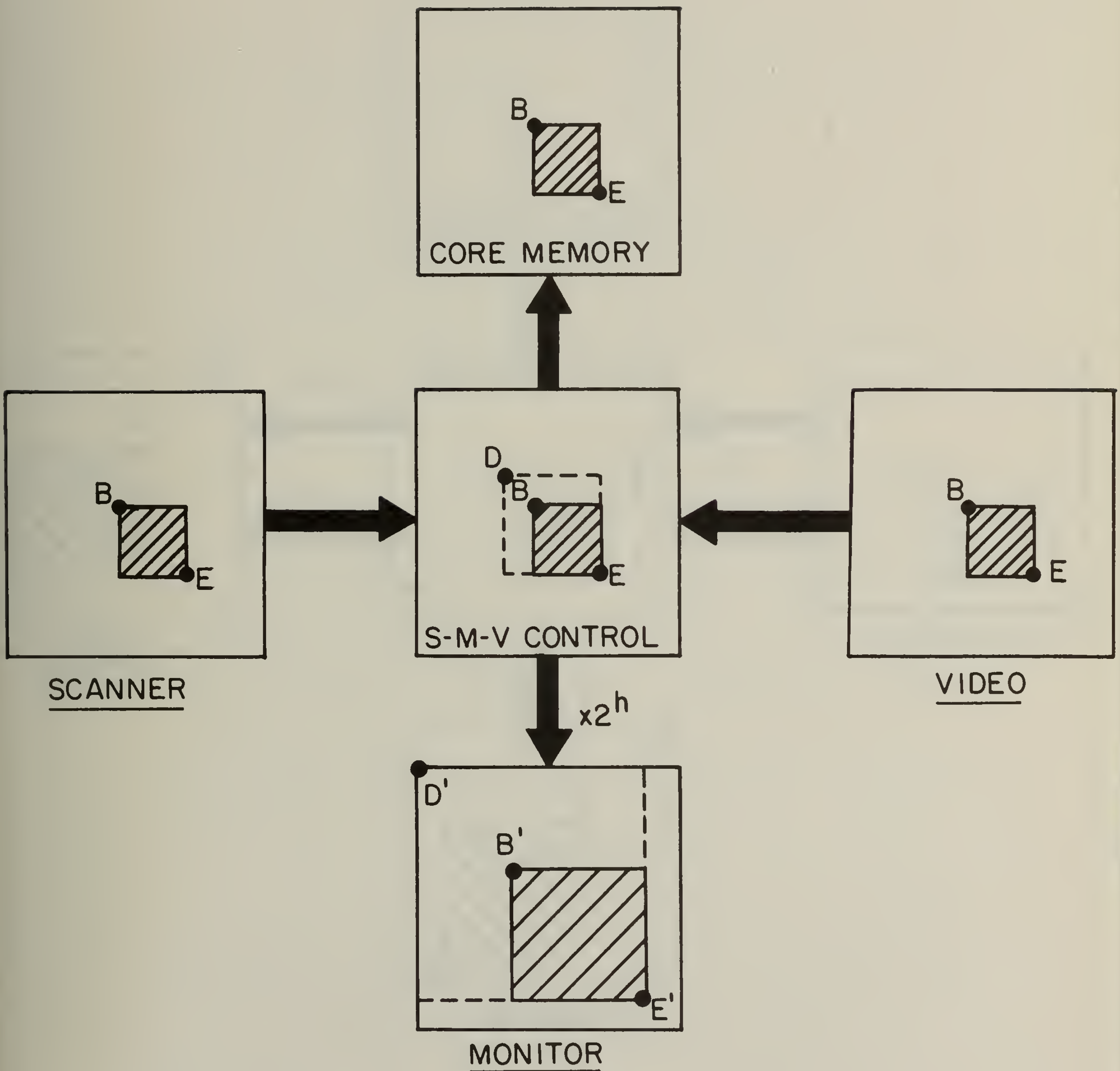


Figure 15 - Magnifying a Window at the Monitor and/or Transmitting to Core Memory

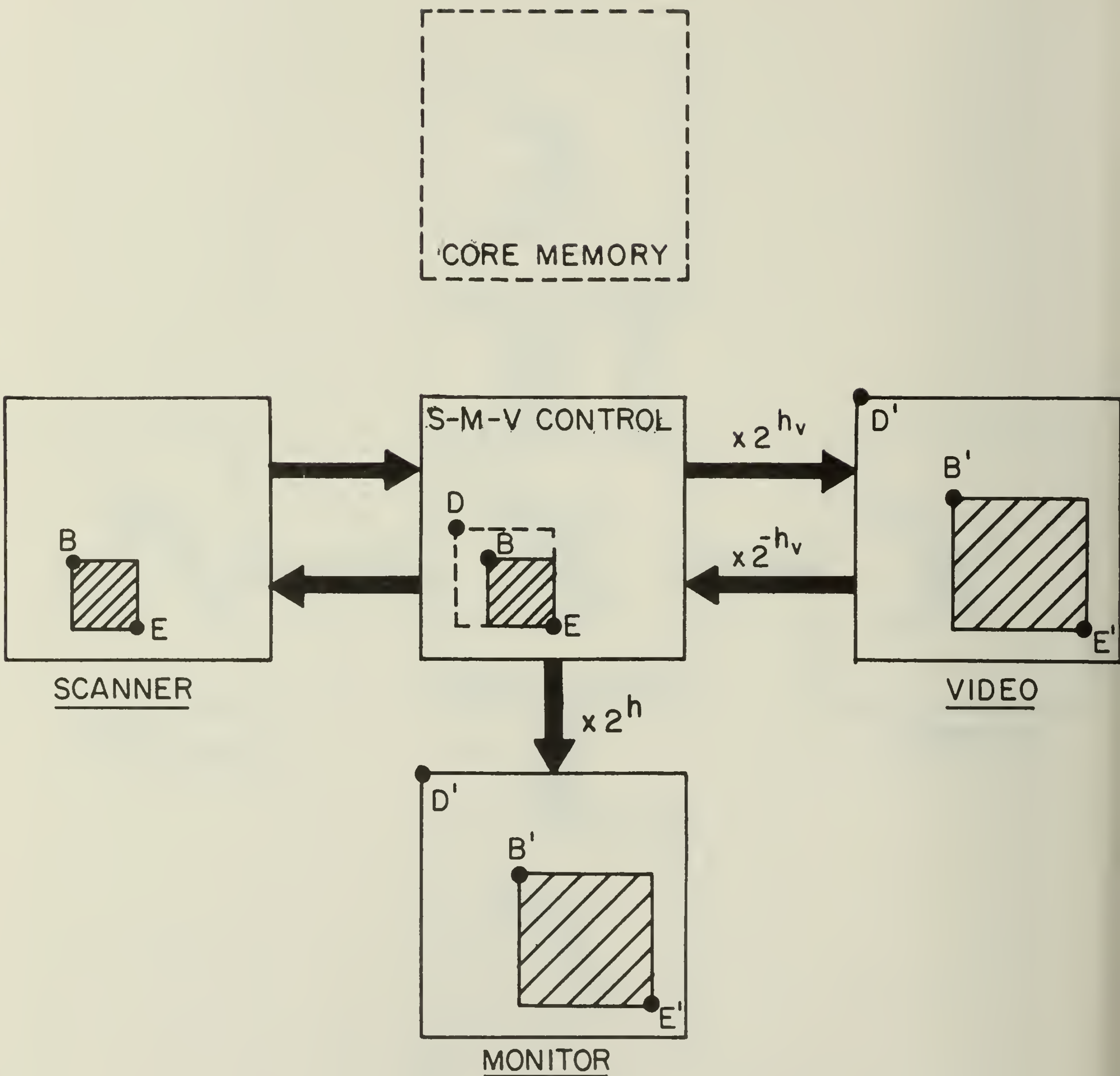


Figure 16 - Transmitting Between Scanner and Video. Display at the monitor with $h = h_v$

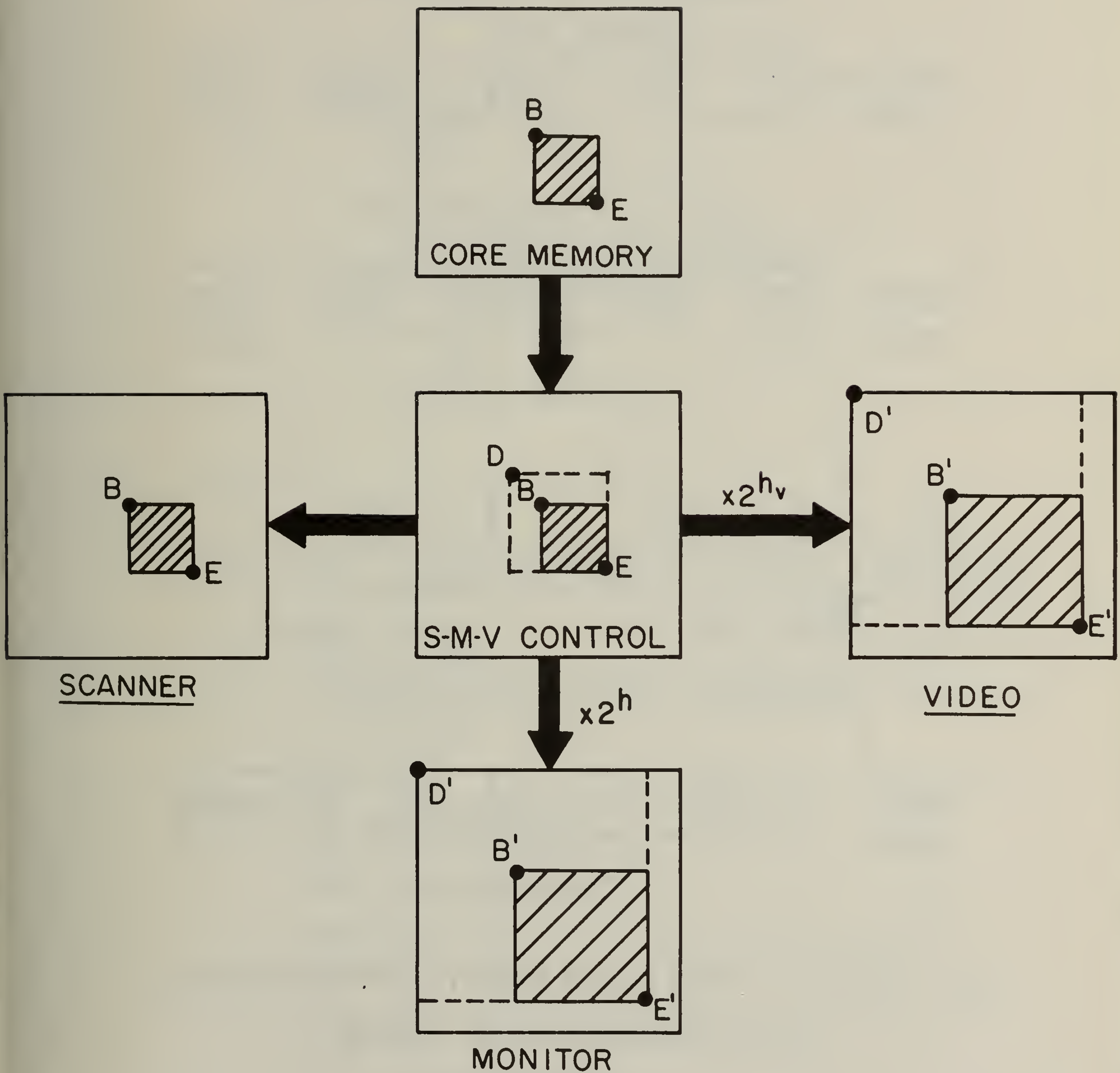


Figure 17 - Transmitting From Core Memory to One or More Media. If to video, $h = h_v$.

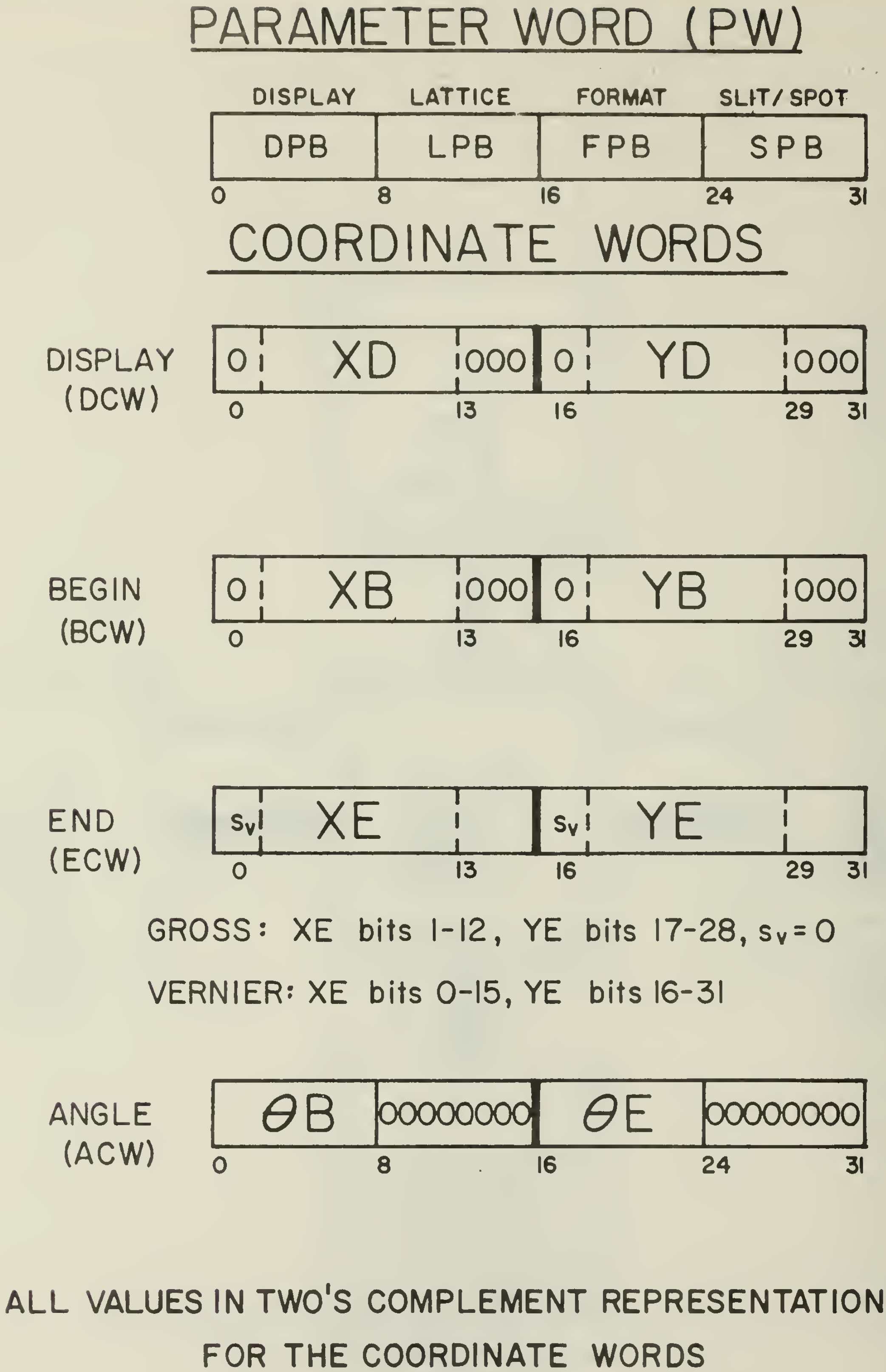


Figure 18 - Parameter and Coordinate Words Formats as Defined for Illiac III

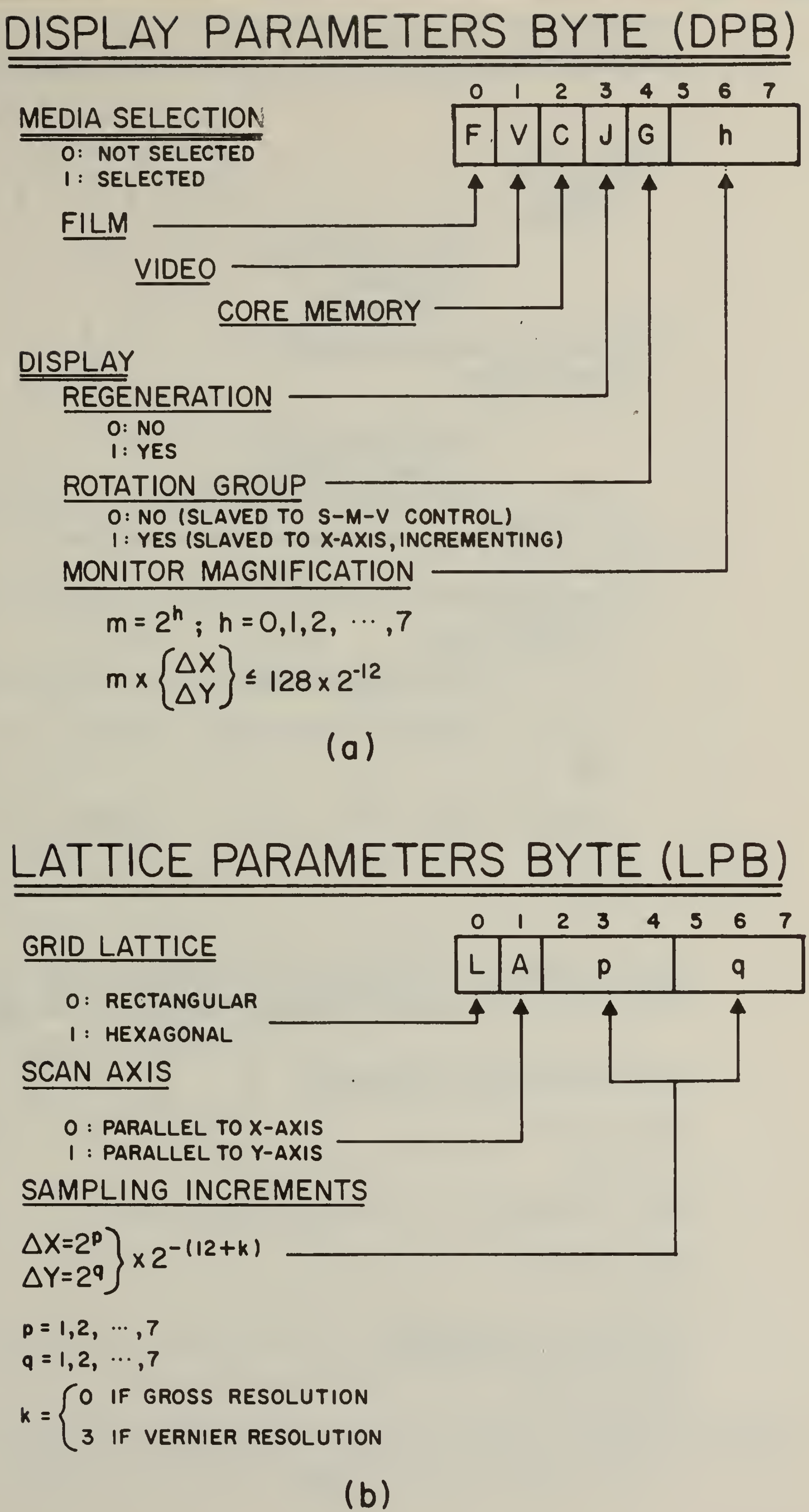


Figure 19 - Display (a), Lattice (b) Parameter Bytes as Defined for Illiac III

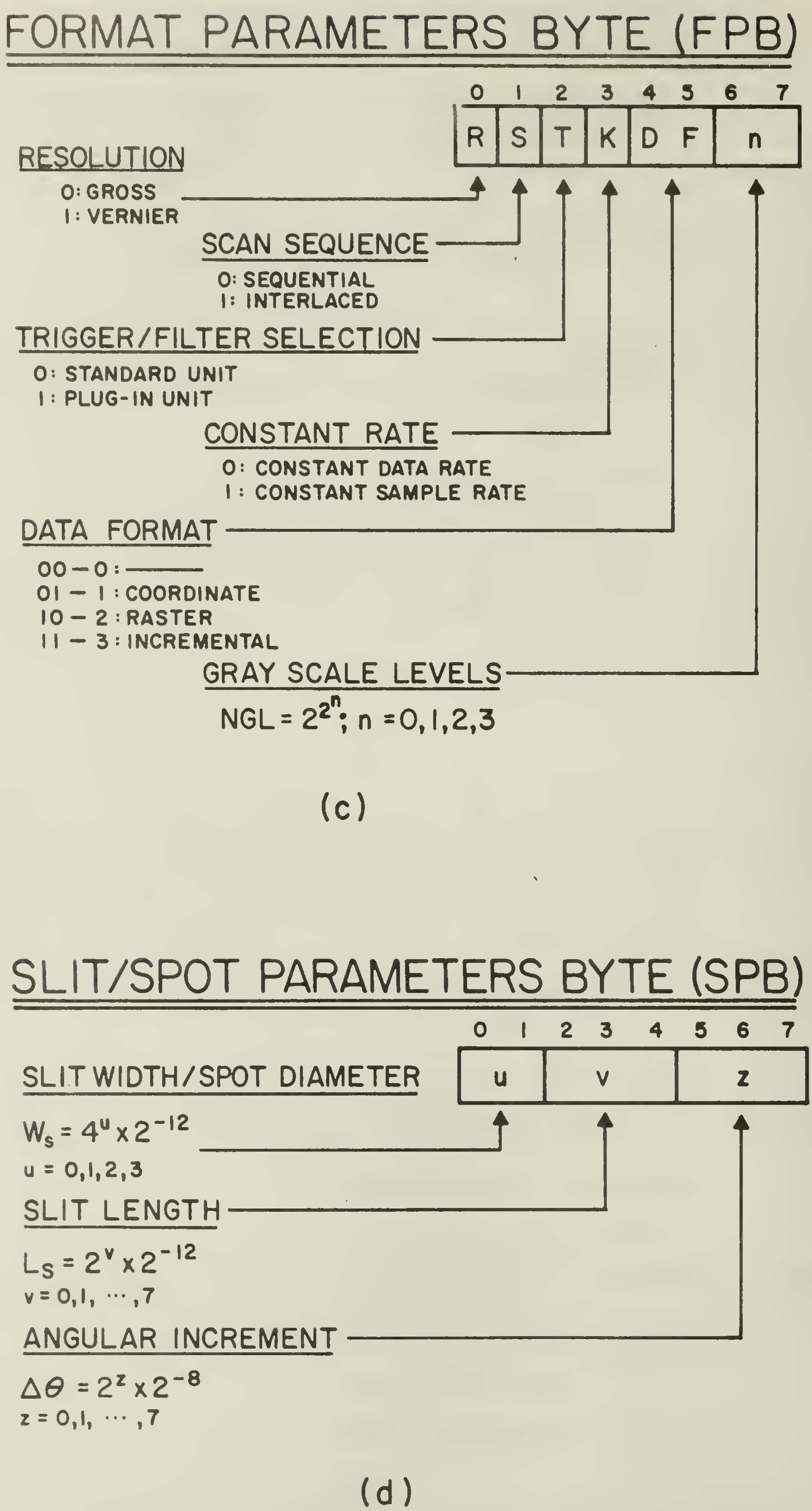


Figure 19 - Format (c), and Slit/Spot (d)
Parameter Bytes as Defined for Illiac III

i	$N(i)$	$\Delta t(i)$ μ-sec	$S_{max}(j)$	j
1	525	≈ 56	512	9
2	1536S	≈ 520	4096	12
3	1536F	≈ 43	256	8

F = FAST SCAN

S = SLOW SCAN

Table I - Inherent Characteristics of Three Video Systems and Maximum Sampling Resolution, $S_{max}(j)$, as Constrained by Other Media

j	n				g(j)
	0	1	2	3	
9	512 (8)	256 (16)	128 (32)	64 (64)	0
12	4096 (1)	2048 (2)	1024 (4)	512 (8)	-1
8	256 (16)	128 (32)	64 (64)	32 (128)	3
	1	2	4	8	
	2^n, bits of gray scale				

Table II - Maximum Sampling Resolution and Interdependence of Position and Gray Scale Resolution as Constrained by Media Characteristics
The main entry is the maximum number of samples per video scan line, $S(j,n)$, and the value in parenthesis is the corresponding maximum value of ΔX, $(\Delta X)_{max}(j,n)$.